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About ASI Kolkata Chapter

The Analytics Society of India (ASI), Kolkata Chapter is mentored by its parent body - ASI at the Indian Institute of Management Bangalore. ASI is the largest body of analytics professionals and organizations in India. The society has been founded by eminent personalities from the Indian Institute of Science, Bangalore (IISc) and the Indian Institute of Management, Bangalore (IIMB) to promote and propagate knowledge in analytics. Various blue-chip corporate organizations, educational institutions, and individuals from across the country are members of this society. ASI provides a platform for organizations and people to come together to share their knowledge, and resources and address their challenges in the analytics field. It promotes research and application in this domain.

Analytics Society of India – Kolkata Chapter intends to nurture the culture of Data Analytics. The chapter intends to:

- Enable organizations to gain value from data exploration, data mining, inference,and applications.
- Bring data analytics education to the city, build community, promote research,and analytics advocacy.
- Bridge the gap between academia and industry.
- Help students and professional to build a career in Analytics by:
    - Participating in various events such as Webinars, Masterclasses, Datathons, Symposium and Workshops.
    - Availing Internship opportunities for deserving candidates.

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Message from the Trustee Board Member

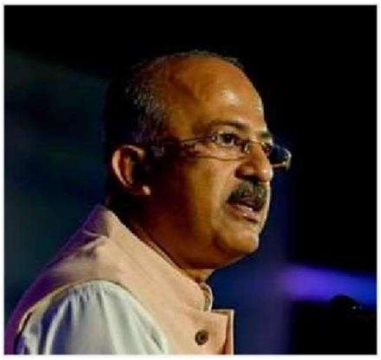
Artificial intelligence is gaining importance in businesses, society, and our everyday lives. In our Institute for Computing and Analytics, we encourage students to work on innovative projects to prepare them for the age of Artificial Intelligence. This year, we are launching our very own journal for Computing & Analytics – "Vishleshikaa", at the Analytics Global Conference 2025 (AGC2025).

Vishleshikaa aims to foster a culture of ideation and innovation, an effort to take learning beyond the curriculum. I wish the AGC2025 team and the Vishleshikaa Editorial Team all the success.

Sincerely,

Mr. Dharmen Trivedi
Trustee Board Member
Bhawanipur Gujrati Education Society

Message from Chief Mentor, NSHM Knowledge Campus



Dear Students and Researchers,

I am thrilled to introduce Vishlesikhaa, a pioneering initiative that showcases the outstanding research work of students in the field of analytics. As we are launching Vishlesikhaa for the first time at the Analytics Global Conference 2025, I am filled with pride and excitement.

Vishleshikaa represents a significant milestone in our efforts to foster a culture of research and innovation among students. This platform will provide a unique opportunity for young minds to share their ideas, collaborate with peers, and learn from experts in the industry.

As students, you are the driving force behind Vishleshikaa. Your curiosity, creativity, and passion for research will shape the future of analytics. I encourage you to embrace this opportunity with enthusiasm and dedication.

Through Vishleshikaa, I urge you to:

- Explore new ideas and perspectives
- Develop your critical thinking and problem-solving skills
- Collaborate with peers from diverse backgrounds
- Learn from experts and industry leaders
- Showcase your research and innovations to a global audience
- Create products and services to solve problems

Remember, research is a journey, not a destination. It's about asking questions, seeking answers, and pushing the boundaries of human knowledge.

I am confident that Vishleshikaa will become a catalyst for inspiring future generations of researchers and analysts. I look forward to witnessing the incredible work that will be showcased.

Best wishes to all the participants, and I wish you a rewarding and enriching experience.

Sincerely,

Mr. Cecil Antony
Chief Mentor
NSHM Knowledge Campus

Message from the Chief Editor, NSHM Knowledge Campus

Analytics Global Conference 2025 (AGC2025) is the third conference of the AGC series. The theme for AGC2025 is Human-centered Data Analytics: Technology for Sustainable Development. The conference aims to promote industry-academia collaboration for analytics. It is my pleasure to see the enthusiasm it has generated among the scholars and professionals and the large number of papers submitted for the conference. Analytics Global Conference offers students, scholars, and faculty members a great opportunity to present and publish high-quality research work. We hope to see a significant increase in the quantity and quality of submissions over the years.

This year we are starting our very own Computing & Analytics journal named "Vishleshikaa". The name Vishleshikaa is derived from the Sanskrit word Vishleshan (विश्लेषण), which means analysis. The journal aims to nurture students' interests, promote knowledge, and inculcate ideation abilities for an improved learning experience. The journal aims to be a cornerstone for promoting culture of using Computing technology and Analytics for societal good and economic growth.

The first edition of Vishleshikaa showcases ebullient efforts by students in making a scholarly contribution. It serves as evidence of the analytical power of young minds and their endeavour to go beyond the curriculum to garner knowledge. The editorial team extends whole-hearted encouragement to all authors of Vishleshikaa and wishes them the very best in their future endeavours.

As artificial intelligence is becoming a mainstay of our daily lives, the domain of data science, machine learning, deep learning, and their applications will gain increasing importance. Analytics, machine learning, and artificial intelligence will continue to change lives and lifestyles. There is an immense need for quality research and innovation in this field. Vishleshikaa is an effort to usher in an ecosystem of research and innovation for higher learning.

Prof Suparna Dhar
Chief Convener AGC2025
Principal, NSHM Institute of Computing & Analytics,
NSHM Knowledge Campus

Contents

Comparative Analysis of Sentiment Analysis based on tweets: Procedure, Various Approaches and its Challenges

Tiyashi Chatterjee, Atri Sanyal
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Abstract

X Sentiment Analysis has become a pivotal area of research aimed at classifying tweets under categories based on the sentiments they seem to convey. It has often been used in understanding public opinion or user's response to various products, political elections, and predicting social and economic phenomenon such as stock market trends. The primary focus on X (previously known as Twitter) branches out from its vast and colossal user base, generating over 500 million tweets on a daily basis, providing a very rich and abundant source of data required for Sentiment Analysis. The primary approach involved or used towards Sentiment Analysis can be divided into a two-step process, firstly collecting tweets and then classifying its sentiment score otherwise known by polarity as positive, negative, or neutral. Various techniques such as Lexicon-Based Approaches and Machine Learning-Based Approaches have been used time and time again to achieve a more accurate and precise analysis on the tweets. Various challenges are also encountered when it comes to perform sentiment analysis on X (previously known as Twitter). One of the primary and demanding challenges of Sentiment Analysis is understanding the nuance behind a given piece of text. Other challenges such as word limit, emoticons continue to exist. Despite the progress that has been made in Sentiment Analysis of user responses and other text sources, sites such as Twitter present this unique challenge of understanding the nuance or the brevity of tweets. We have tried to compare the performance of some of the most widely used approaches for Sentiment Analysis based upon certain parameters. Finally, concluded that there is no clear winner among different approaches. Each approach has its own advantages and disadvantages and the choice depends on the type and uniqueness of the problem to be solved.

Keywords

Sentiment Analysis, Machine Learning, Lexicon-Based Approach, Twitter Data, Performance Metrics.

Introduction

Sentiment Analysis can be described as a field at the intersection of Natural Language Processing (NLP), Text Analysis, and Lexicon Understanding, playing an important role in identifying and providing sentiment scores to a piece of textual data. It involves the use of various algorithms, approaches and techniques aiming at determining whether a piece of text conveys positive, negative, or neutral emotions [2]. X (previously known as Twitter) a widely known, popular microblogging platform with a whopping 613 million user base, has become a focal point for Sentiment Analysis due to its user base, the number of tweets generated daily and the concise nature of tweets, being limited to 280 characters [7]. Twitter Sentiment Analysis aims to analyze the sentiments expressed in tweets to understand public opinion, consumer feedback, political views, and more. Using and combining machine learning algorithms and Lexicon-based approaches, Sentiment Analysis on Twitter can provide valuable insights or data for various domains. When saying that the analysis of sentiments on Twitter can help various domains, it can range from businesses in shaping their marketing strategies, monitoring brand perception, and gauging customer satisfaction to politics where Sentiment Analysis on X can help track political views. The challenges in Sentiment Analysis on Twitter stem from the brevity of tweets, cultural nuances, and the complexity of human language. The primary difficulty lies is understanding the emotion behind a given piece of text. Despite these challenges that continue to grow stronger with each passing day, sentiment analysis on X has proven to be a vital and useful tool for capturing the general mood of the online community. People have continuously been exploring innovative methods to enhance the performance of Sentiment Analysis on X, making it a dynamic, interesting, and evolving field in the realm of social media analytics [8].

Flow of Work while implementing Sentiment Analysis

No matter the approach is used for Sentiment Analysis, there exists a certain process that must be followed when building the model. The attached figure below will help us to get a primary idea of how one shall begin working.

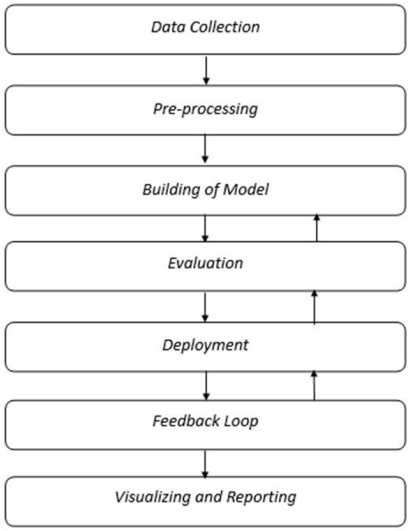

Figure 1: Flow of Work to Implement Sentiment Analysis

The above figure gives an estimated idea of the flow of work involved when building a Sentiment Analysis Model. Further, we will briefly see what happens at each step of the work flow.

1. Data Collection-Raw data is collected from X (previously known as Twitter). It can be done in primarily three ways-
   a. Using Twitter APIs such as 'Tweepy' and 'X API'
   b. By manually handpicking tweets from users and then creating a .csv or .xlsx file to store the tweets.
   c. Building a web scraper and storing data form a specific webpage by providing url.
2. Pre-Processing-Primarily involves getting rid of irrelevant, incomplete and duplicate data. It can be done in any of the following ways or all of them-
   a. Cleaning of Text-Involves removing mentions, hashtags, special characters etc. It involves handling of emoticons.
   b. Tokenization-It involves breaking down a piece of text into individual words or tokens.
3. Building of Model- Involves selecting one or combining more than one approach based on the requirements behind performing Sentiment Analysis. There are various approaches that can be used to build a Sentiment Analysis Model. Some of the most widely used approaches are-
   - Machine Learning Based
   - Lexicon Based
   - Ensemble Based

However, when conducting a comparative study, it has been seen that all approaches have their own sets of advantages and disadvantages, strengths and weaknesses [9]. Based on user requirements, any of the approaches are selected to build a Sentiment Analysis model.

It is important that we train the model for the data it may face when performing Sentiment Analysis on real life data. This involves feeding the data to the model, allowing it to find patterns and relationships between textual features and sentiments.

4. Evaluation- When building a Sentiment Analysis model, it is a crucial step that needs to be executed before the model is sent out in the real world to function. In this step, we primarily evaluate the said model by working with trial datasets. - Performance Metrics- Even though choosing the approach for Sentiment Analysis may differ for various requirements, it is pivotal that we compare the performance metrics to ensure that the model is best fit for the requirements. Some of the mostly used Performance Metrics used are-
   a. Accuracy
   b. Precision
   c. Recall
   d. F1-Score
6. Deployment- It is essential that once the model has undergone performance metrics such as Accuracy, Precision, Recall and received a satisfactory score, we deploy the model to see if it can handle real-life data as smoothly as seen in case of Evaluation and Deployment.
7. Feedback Loop- Once the model has undergone its deployment and evaluation, we can

or may need to train the model again by refining it further or make adjustments to achieve a better performance score and to help the model perform better. This loop is known as Feedback Loop[1].

Approaches and factors affecting Sentiment Analysis

While there are various approaches that exist for Sentiment Analysis, there are several factors that must be taken into consideration to receive better outcomes. Some of these factors are-

1. Data Quality and Quantity- Data is the very core and base for Sentiment Analysis. Hence, it is extremely crucial for the data that has been collected to be complete, accurate and relevant, as it can and may influence or alter the result of Sentiment Analysis. As important as the Data Quality is the Data Quantity. It is pivotal that we take more than enough data points so that the result of the Sentiment Analysis

model is not biased towards a particular sentiment polarity [6].

2. Data Cleaning- When collecting Data with the help of Twitter APIs or manually hand-picking them, there is a high possibility of finding irrelevant data, incomplete data, duplicate etc. If such data is not processed cleaned or removed properly, this data may affect the result and play a role in altering them. There are various techniques for Data Cleaning, some of the most widely used ones are
   a. Removing Duplicates
   b. Remove Irrelevant Data
   c. Standardize Capitalization
   d. Fix Structural Errors
   e. Delete Outliers, if any
3. Domain Specifications- When working with such voluminous amounts of data, it is extremely important that one is knowledgeable or aware of which domain they want to work with. Doing so can help filter the data as deemed necessary for the requirements. Not having a clear idea of the domain may require much more computational time and resources.
4. Ethics and Privacy-When working with data compiled or collected from social media, it is extremely crucial that we maintain, respect and give importance to user privacy as well as its other counterparts such as confidentiality throughout the entire process of Sentiment Analysis.
5. Evaluation of Model-There are various techniques that can be used to evaluate the performance of a model. Some of these are, Accuracy, Precision, Recall and F1-Score. It is crucial that the model's performance receives a satisfactory score when tested with these metrics, before being deployed.

Scope for Improvement- A Sentiment Analysis model may undergo changes and improvement, which may be iterative in nature as stated for the Feedback Loop, for the model to keep up with its performance, feedback etc.

A Comparative Study on the Various Approaches

Criterion	**Lexicon-Based Approach**	**Machine Learning-Based Approach**	**Ensemble-Based Approach**
Accuracy & Scalability	Might lack accuracy when handling complex language details.	Can achieve higher accuracy as they capture complex sentiment ex- pressions.	Outperforms individual models by combining predictions from multiple base models [4][5]
Interpretability	Offers high interpretability since sentiment scores are associated with words or phrases in the lexicon.	These models vary in interpretability. Ex: Decision trees are more interpretable compared to deep neural networks.	Ensemble methods sacrifice interpretability over accuracy.

Adaptation to Domain	They struggle with domain adaptation.	Can adapt to various domains with appropriate datasets and fine-tuning.	Can improve domain Adaptation by combining predictions.

Table 1: Comparison of different sentiment analysis approaches.

While all of the approaches have their own set of strengths and weaknesses, it is extremely crucial that the type of data provided and the requirements are well defined [10][11] Depending on the requirements one can choose to opt for one of the given approaches or a combination of them. However, it is crucial that the performance remains high.

Basic Sentiment Analysis Models used in Various Approaches

I. **Lexicon Based Approach**-This approach in Sentiment Analysis relies on the usage of a dictionary which contains either words or phrases annotated with sentiment scores. These sentiment scores define the word or phrase's polarity, indicating at the sentiment it carries which can either be positive, neutral or negative [3].
Advantages-

1. Legible in nature- Lexicon Based Approaches provide transparent and understandable results. The dictionary used contains sentiment scores that are readable and understandable to the human mind.
2. No Training Required- Lexicon Based Approaches do not require any training on labelled datasets, which can prove to be time consuming and may use up a lot of the resources and can also work with labelled and unlabeled datasets alike.
3. Medium Resistant to Noise- Lexicon Based Approaches can handle spelling errors and other grammatical mistakes as long as the sentiment determining phrases are available in the piece of text.

Disadvantages-

1. Lack of Robustness- Lexicon Based Approaches rely heavily on the available set of words or phrases available in the dictionary. Lack of coverage of words or phrases in the dictionary may cause the Sentiment Analysis system to provide less accurate results or even fail, making it less robust to handle all cases.
2. Scalability- Lexicon Based Approaches have proven to be efficient for small to moderate sized datasets, and may not perform as well with large or voluminous datasets.

II. **Machine Learning Based Approach**- This approach in Sentiment Analysis relies on training models to learn and recognize patterns and relationships in a given piece of text and further used to predict sentiment polarity i.e. positive, neutral or negative.

Advantages-

1. Flexible in Nature- Machine Learning Based Approaches have the ability to capture and understand more complex patterns in a given piece of text.
2. Accuracy- Since Machine Learning Based Approaches have been trained on large and a variety of datasets, they can achieve a much higher accuracy rate and have proven to be scalable.
3. Adaptive in Nature- Machine Learning Based Approaches tend to be adaptive in nature, which allows them to be re-trained with new data to be at par with changing patterns in text.

Disadvantages-

1. Problem of Overfitting- If Machine Learning Based Approaches catch noise or irrelevant data, it can overfit itself to the given data, affecting its performance.
2. Complexity in Calculation- Using Machine Learning Based Approaches with a vast number of features can take up a lot of time and resources.

III. **Ensemble Based Approach-** Ensemble Based Approaches rely on combining various in- dividual classifiers and models alike to improve accuracy and performance. Combining more than one model or classifier helps overcome individual shortcomings and hence promise a better performance altogether.

Advantages-

1. Higher Accuracy- Since Ensemble Based Approaches usually combine more than one classifier or model, it promotes a higher rate of accuracy.
2. Combining Predictions- Several prediction methods are combined to make the final sentiment predictions. Methods such as Voting, Stacking, Boosting etc. are used.
3. Reduction in number of predictions- Ensemble Based Approaches average or combines multiple individual predictions, resulting in taking into consideration all the predictions made by individual models.

Disadvantages-

1. Reduced Interpretability- Ensemble Based Approaches often forsake interpretation for increased accuracy rates.
2. Increase in Complexity- Combining two or more classifiers or models make the process of Sentiment Analysis using Ensemble Based Approaches much more complex.

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A Review of Literature on Various Challenges and Opportunities of Quantum Computing

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Abstract

Quantum computing is reforming the way we address complex computational challenges by offering unparalleled speed and efficiency. Quantum computing is a technology that invokes the use of qubits instead of ordinary bits to solve computational problems, that would take supercomputers, millions of years to complete, in just a few minutes. Quantum computers use the idea of superposition to solve problems. The theory states that a qubit can either be in a state of 0 or 1 or both. While it increases the computational speed, quantum computing also comes with its set of implementation challenges because of its complexity. These challenges usually include security concerns, lack of standardization, quantum error correction, and software and algorithmic limitations among many others. Advancements have now been made for standardization efforts and quantum error corrections. The development of quantum cryptography has also laid the path for secure communications.

Keywords

Quantum computing, Noisy intermediate-scale quantum (NISQ) systems, Quantum Algorithms, Quantum error correction, Quantum Hardware and Quantum Simulations.

Introduction

The dawning of quantum computing in the field of technology marks the beginning of a revolutionary eon in information technology, leveraging principles of quantum mechanics viz. superposition and entanglement to solve classically intransigent problems. Current development especially in Noisy Intermediate Scale Quantum (NISQ) systems highlights both the immense potential and the technical challenges of quantum technologies. Topics like cryptographically discovered algorithms, quantum simulations, industry use cases in optimizations, machine learning, and material science quantum computing are set to reformulate computational limits across various sectors. Nonetheless, approving this approach requires going through significant obstacles such as error correction, scalability, and material challenges in hardware

development. This review delves into the current scenario in quantum computing deriving acumen from emerging applications, hardware innovations, and inter-disciplinary research to draw a roadmap of the opportunities and limitations shaping the future of this department.

Literature review

In [1] the author examines the challenges and opportunities associated with near-term and noisy quantum computing applications, thus engaging with IMB's proposition to advance in accessibility and functionality. This paper highlights five key areas: (i) User-Friendly cloud access, (ii) The QISKIT Software Development Kit, (iii) Benchmarking through Quantum Volume, (iv) Error Mitigation techniques, and (v) Early quantum Applications like Quantum Machine Learning and Quantum Chemistry. The paper emphasizes IBM's commitment to the User-Centric Approach providing diverse access interfaces for Quantum Physicists, Scientists, and Developers, and supporting research through open access to Data and Metrics. This paper highlights the importance of hardware-aware compilations and optimization strategies that are tailored to noisy intermediate-scale Quantum (NISQ devices), which usually consist of tens to hundreds of qubits. To maximize hardware efficiency techniques such as approximate compilation and quantum volume are presented. Error mitigation methods usually include zero-noise extrapolation and probabilistic error cancellation extending computational reach until fault-tolerant quantum systems become feasible. This paper sifts through promising near-term applications like using quantum machine learning for evaluating complex feature maps and quantum chemistry for estimating ground-state energies with variational Quantum Eigen solvers. The author discusses IBM's use of Superconducting Transmon qubits along with hardware engineering challenges which also include microwave engineering and system reliability. Finally, the paper summarizes the potential of NISQ devices to drive innovation while also addressing the limitations of current quantum hardware.

According to Paper [2], the authors, post examination of the massive development that has come about Quantum Computing, suggest about its capacity for varied applications and constitutional principles that enable it. The Theory of Quantum Computing utilises the principles of Superposition and Entanglement to achieve computational goals that are not feasible for classical systems to perform. Alternatively, Qubits exist in multiple states at the same time, together, which in turn immensely enhances the computational power. The authors also shed light on the importance of Quantum Algorithms such as Shor's Algorithm, according to which there is a major challenge for today's cryptographic systems, and that is because of factorisation. A quadratic acceleration of search of unstructured data is permitted by some algorithms, here, for example, The

Grover's Algorithm. Apart from that, the authors have also looked into real-world applications like logistics, financial risk analysis, random number generation, satellite communications, etc. They assume that Quantum Algorithms possess huge potential for enhancement of performance in different domains. Techniques such as Adiabatic Quantum Computing, The Harrow-Hassidim-Lloyd (HHL) algorithm, and Quantum Annealing justify challenges like Constraint Satisfaction Problems, Linear System Solutions and Optimization Challenges. Quantum Simulators based on Richard Feynman's vision, grant researchers to understand complex quantum mechanical systems using tens of qubits therefore evading the extreme difficulty suffered by classical simulators. These techniques bring about improvements in operations like Quantum Magnetism and co-related electron systems. The challenges faced are noise, hardware reliability, algorithm development, etc are integral faltering points. Real-world issues of quantum systems are still coming up, with results expected in fields which require high computational power. Quantum Neural Networks and Hidden Quantum Markov Models (HQMMs) expand on the current efforts to exploit quantum mechanics for tasks like natural language processing and sequential data modelling. Conclusively, the paper illustrates the ground-breaking potential of quantum computing in ameliorating computation across scientific, industrial and technological domains.

In [3] the authors examine the operation of QUTAC, which stands for Quantum Technology and Applications Consortium. It is a German Consortium of ten major companies that range from industries like automotive, chemicals, pharmaceuticals, and insurance to technology. It aims to accelerate the industrialization of Quantum Computing (QC). The paper advocates for an application-centric approach, ranging from hardware-focused development to dealing with high-impact industry problems. QUTAC aims to guide technological progress and drive QC commercialization by creating industry reference problems and benchmarks. This process faces key challenges including proving QC's business value and integrating it into existing processes, establishing effective benchmarks, and fostering cross-industry collaboration to share expertise and de-risk investments.

The author describes how QUTAC emphasizes the relevance of application-specific benchmarks that extend beyond hardware metrics to assess QC performance meaningfully. Reference use cases are proposed as structured frameworks which include business value assessments, problem analysis, mathematical formulations, and verification routines to enable comparative evaluation of QC solutions. The consortium helps to identify significant challenges in quantifying QC's impact as a result of dependencies on technical and business factors. While applications like quantum-mechanical simulations have medium-term potential, applications like engineering

simulations have longer-term prospects. To advance QC adoption the authors of this paper recommend prioritizing the development of industry-relevant benchmarks, demonstrating tangible business impacts, and fostering ecosystem-wide collaboration. They aim to deliver talent amplifications, education, and the making of industry benchmarks to ensure that QC solutions correlate with real-world problems. Despite the challenges suffered, the scope for metamorphic leverages in sectors like material science, logistics, and engineering accentuates the need for a unified and application-driven attitude toward QC industrialization.

According to paper [4], the authors shed light on the importance of material science in advanced quantum computing. It elaborated that material selection and optimization and critical elements for the improvement of solid-state qubits. The paper illustrates the influence of material science on various qubit platforms, namely superconducting circuits, quantum dot spins, colour centres, etc. Material Sciences have assisted in examining important metrics for assessing qubit performance, which includes coherence time, gate fidelity, gate duration, quantum error correction, etc. Apart from this, the authors also explain about the different physical platforms utilised in quantum computing, like superconducting qubits, which are based on Josephson Junctions for their non-linear elements. They come across various issues, such as defects and noise, which takes a toll on their performance. Challenges such as nuclear spin fluctuations and charge traps take place when the quantum dot bits, which rely on electron or hole spin states, are restricted within semiconductors. Colour centre qubits rely on impurities present in the host crystals. One such example is in the case of diamonds. They face problems such as paramagnetic impurities and surface issues. Trapped ion qubits are separated from noisy environments, which may be affected by material considerations face issues like electric field noise and drift. The paper also elucidates the protocol for the synthesis of each qubit type. The various qubit types that can be synthesised are E-BEAM lithography for superconducting qubits, reactive ion etching for quantum dots, chemical vapour deposition (CVD) for colour centres, CMOS/MEMS technique for ion traps, etc. They target the multi folding importance of hole spins in SI and GE quantum dots as an emerging venture for upgradation of coherence time and spin controls. Ultimately, the authors advocates that the revolution in all qubit platforms depends on the availability of high-purity materials and state-of-the-art processing protocols to enable the betterment of intermediate scale quantum systems.

According to paper [5], the authors have explored the prospect of quantum computing improving Machine Learning (ML) tasks by taking the help of near-term devices with hundred to thousand qubits. This advocates the need of enumerating stubborn ML challenges such as use of generative models in an unmoderated methodology of learning and the utilization of datasets with critical quantum-esque correlations. These

areas grant quantum computers to equip meaningful insights by performing efficient, sampling complex probability distributions, representing data compactly and accurately, etc. The paper puts forward an argument that hybrid classical-quantum algorithms, in which quantum strengths deal with computationally comprehensive tasks within an ML pipeline, are crucial for leveraging the strengths of the ongoing quantum devices.

The paper elucidates certain challenges such as noise, limited connectivity, efficient data representation for quantum processors, etc, which implies solutions like "semantic binarization" and the Quantum-Assisted Helmholtz Machine (QAHM). QAHM puts together traditional deep learning, also known by, initial data processing, and quantum computing to model the most abstract data representations. When they are put together, it promises a more realistic path for surmounting the shortcomings of near-term quantum devices. The paper has provided a roadmap for identifying applications in quantum-assisted ML by detailing difficult ML tasks, hybrid solutions, and highly specialized datasets. This ground-breaking revolution goes beyond the limitations of conventional ML algorithms to attain the much sought-after quantum advantage.

The authors have suggested the result of specifying real-world datasets where quantum models have performed significantly better than the traditional classical models. This phenomenon is usually more common in sectors that are unrelated to Quantum Physics. Proclaiming quantum excellence in practical as well as real-world scenarios is a very critical step as it demonstrates the importance of Quantum-Assisted Machine Learning with near-term devices. They are upholders of inter-disciplinary participation as it helps in determining the high-value issues that meddle with quantum computing's capacities. Finally, the paper also sheds light on the utilization of the newest hybrid algorithms that can be integrated both effectively and seamlessly into both quantum and classical components. This ensures compatibility and efficient flow of information between the two systems.

According to paper [6], the authors have explored the groundbreaking possibilities and variety of use cases of quantum computing technology. Specifically in databases, at the same time detailing the various techniques, problems and algorithms. There have been many innovations in areas of supercomputing and trapped ion quantum computers. The systems run in the Noisy Intermediate-Scale quantum (NISQ) era. While they are powerful, they are extremely prone to errors. Here critical quantum computing concepts such as qubits, superposition and quantum gates are elaborated with specific importance to paradigms like Quantum Annealing and Grover's Algorithm, the latter providing a noticeable speed-up in database searches and optimization.

The paper puts forward a fascinating opportunity for databases using quantum computing while including improved query optimization, database manipulation and data security through quantum cryptographic algorithms. Algorithms such as QAOA and VQA are utilized for optimization. On the other hand, quantum-based security protocols like QKD and Quantum Private Queries provide protection at the advanced level. These days hybrid traditional quantum techniques are also coming forward to deal with issues caused by a limited number of qubits and noise, therefore quantum-based approaches act only as a temporary solution to help in the betterment of classical systems for resource allocation, keyword searches, and retrieval of information.

Conclusively, the authors have suggested various ingenious designs for quantum databases along with quantum vectors and distributed graph databases, which provide better efficiency, data security, and scalability.

In [7] the authors analyze the capabilities of quantum computing systems in finding the solution to complex optimization problems for energy systems. As the energy demand grows and renewable resources unify traditional optimization problems have started to cease due to the computational complexity of problems like facility location allocation, unit commitment, and heat exchanger network synthesis. To solve these issues, quantum computing uses phenomena like superposition and entanglement which essentially offers a different and more efficient approach for solution spaces. This paper features quantum annealers and gate-model quantum computers, particularly for optimization tasks. Limitations of hardware give rise to the need for hybrid classical-quantum approaches.

Despite all the possible advancements, quantum computing is still an emerging field. It often faces problems of limited scalability, precision issues, and error susceptibility which curbs its immediate application, compared to classical computational systems with are optimized for current hardware systems. This paper draws attention to the relevance of hybrid methodologies which bridge the gap between quantum and classical systems and lead the way for dynamic and real-time optimization in energy systems.

In [8] the authors of the paper probe into the evolution of quantum computing and its potential in the automobile industry, whilst also addressing challenges, product development, and Industry 4.0 applications. Factors like integration of disciplines, extensive software in vehicles, and the gradual advancement toward electric vehicles give rise to challenges such as the growth of complexity in automotive designs, manufacturing, and logistics. The authors suggest using existing problems as a framework to guide quantum computing development, identifying key applications in optimization, quantum chemistry, numerical simulation, and machine learning. This paper raises two specific issues namely (i) robot path optimization, which is formulated

as a Travelling Salesman Problem, and (ii) vehicle configuration optimization, which is modeled as a Boolean Satisfiability problem which when solved using quantum computing reduces computational time and ameliorates problem-solving capabilities.

While quantum computing enables theoretical spurs and advantages over scalability, its advancement in this sector in the present times is limited by hardware constraints. The authors have hence underlined the importance of hybrid-classical approaches. They also highlight the need for standardized benchmarks that are tailored to real-world approaches and cross-industry partnerships to expedite developments. Ultimately, by addressing real-world and industrial challenges, this paper creates a strategic insight for integrating quantum computing solutions into automotive operations, in combination with classical computing systems, thus implementing technology as a long-term enabler for innovation and efficiency in the quantum computing sector.

The authors of paper [9] explore the optimization-focused approach of Quantum Annealing via NASA's encounter with D-wave Quantum annealers. While still in its early stages, the one significant question that comes to everyone's mind is whether quantum computers can truly outperform classical computers. Because of inadequate analytical proof of superiority for many quantum computers, empirical testing is the bottom line to assess their capabilities. Quantum annealing functions by using quantum techniques like tunnelling as a bargaining chip to escape local minima in optimization issues. The process of embedding problems framed in the Quadratic Unconstrained Binary Optimization (QUBO) onto the hardware is rather critical due to the limitations of physical qubits and their connections to the architectures such as the D-wave's Chimera Graph.

Quantum Annealing can be applied in a variety of sectors namely Planning and Scheduling, Allocation of Resources, Fault Diagnostics and Machine Learning. An appropriate example of this is the testing of Quantum Annealers in the optimization of NP-Hard scheduling problems. It was observed that there was an improvement in logistics and air traffic control and provided better assistance in case of disaster recovery. Since then, quantum annealers have also been used to diagnose faulty electrical systems, where the arrangement of the qubits and the circuit's structure mirror each other. Furthermore, applications of Quantum annealing have also been seen in machine learning, especially while training the Boltzmann machines and graphical models. The advantage of using Quantum Annealers in training the Boltzmann machines and graphical models over traditional approaches like Markov Chain Monte Carlo is seen in the efficiency of sampling methods.

The physics that drives Quantum Annealing comprises of Hamiltonian evolution where each qubit starts in a superposition state and then gradually comes down to a

lower energy state representing a solution. To reach our objective of quantum speed-up, the paper lists several bottlenecks such as phase transition and decoherence induced by noise which impacts the efficacy of the work. Some imperative processes for achieving quantum speed-ups include coherent-tunnelling and multi-qubits co-tunnelling. However, these processes too face challenges caused by hardware imperfections and thermal fluctuations, as hardware is dependent on superconducting qubits which with the help of Josephine Junctions facilitate quantum state controls. Various Qubit types, viz charge and flux qubits come with trade-offs in noise susceptibility. Dealing with inter-qubit coupling and mitigation of decoherence continues to be pivotal towards the advancements of quantum annealing technologies.

The authors of paper [10] delved deep into the rising complexity and volume of biological data. This massive explosion in biological data driven by improvements made in omics has also given rise to compelling computational challenges. Quantum computing has proved to be better at handling tasks like protein folding, and multi-scale modelling genome analysis which might often be challenging for classical computers. Even though quantum computing has shown monumental potential in areas of molecular modelling and genome assembly, its practicality remains stifled by hardware limitations such as limitations on the number of qubits and decoherence effects. With these challenges in mind, the paper suggests a hybrid classical-quantum approach. This approach aims to utilize the quantum accelerators for specific subroutines while entrusting classical computers with the overall problem-solving, thus offering the best feasible near-term solutions.

Theories of Quantum Computing that are mostly used in biology include Variational Quantum Eigen solver, more suitable for Noisy-Intermediate Scale Quantum (NISQ) machines, and Quantum Phase Estimation for Molecular Modelling. While exploring Quantum Annealing and quantum approximate Optimization algorithm (QAOA) for genome assembly, it is noticed that Grover's algorithm allows a more promising speed-up for read alignment in genomics. Quantum computing's capability to handle robust correlated multireference systems like the ones found in enzymatic reactions and photosynthesis is a huge benefit for Quantum Chemistry applications. Even with limited practicality, Quantum Algorithms have a rather heuristic approach and are limited only by quantum hardware availability.

Regardless of the challenges faced, quantum computing has shown enough promise in reforming computational biology, particularly in electron structure calculations, genomic data analysis and biomedical imagining. The paper proposes that while the practical use of quantum computing in real-world scenarios is yet not achievable, the hybrid classical-quantum approach may take us a step closer to its practical usage.

According to paper [11], the authors are of the belief that by exploiting the principles of quantum mechanics, namely superposition, interference and entanglement quantum computers can get an upper hand on classical computers to find solutions to problems in various sectors ranging from logistics and drug design to financial modelling and material science. While quantum technology still remains in the Noisy-Intermediate Scale Quantum (NISQ) stage and is dealing with challenges like qubit decoherence and error correction, Google has successfully showcased true quantum supremacy, thus creating a benchmark. The main target, however still remains the solving of real-world problems that are far beyond the capabilities of classical computers. Advancements in Quantum Key Distribution (QKD) and Psot-Quantum cryptography (PQC) systems have become an essential move, as quantum algorithms could easily break encryptions like RSA. Because of this, quantum algorithms like Shor's Algorithm for factoring integers and Grover's algorithm for database searching have more profound implications than before.

This paper also explores various applications of quantum computing in sectors ranging from cybersecurity and medical diagnosis to climate modelling. This further underscores the need for better quantum programming tools like QISKIT and Cirq. Qubit interconnection, infrastructure, energy consumption and even scalability continue to be major obstacles in the development of quantum computers. A few imminent trends are quantum-enhanced AI, the quantum internet and sustainable quantum development. Conclusively, according to Richard Feynman's envisions, nature is inherently quantum mechanics. Thus, only quantum computing can precisely replicate the quantum processes.

In paper [12], the authors discuss the obstacles faced to secure the delegated quantum computers. This additionally emphasises the fact that early quantum computers are more prone to be accessed remotely as servers, thus entailing protocols enabling the computation of encrypted data. This ensures the client has privacy while utilising the resources of the server. The authors have developed a quantum system parallel to a homomorphic encryption system. This new development allows for computations to be processed on encrypted qubits without the need for decryption. The encryption key used by the operators are Pauli X and Z operators which then also decrypts the result with the encryption key which remains unknown to the server. The main motive behind designing this protocol is to make it more efficient as compared to classical computers. The clients are recommended to prepare and send only a single qubit from a set of four possibilities while performing the least classical computations. Furthermore, the complexity is also reduced as no particular quantum computation occurs between the client and the server.

The paper also discussed how the protocol allows in the execution of the Clifford Gates namely X, Z, CNOT, Hadamard, and Phase on encrypted qubits without additional resources, whereas non-Clifford gates call for an auxiliary qubit and limited classical communication. The feasibility of the approach has been verified by showcasing high-gate fidelities for single-qubit operations, with the aid of linear optics. The protocol also lists security concerns such as potential vulnerabilities where encryption keys can be leaked during photon emissions. These risks can be mitigated using improved source and detector technologies. Rather than just offering computational security, this protocol offers a more scalable solution for suture quantum servers by ensuring information-theoretic. Ultimately, this method takes a monumental step towards quantum computing and security by minimizing resource overhead and guaranteeing s strong security solution.

According to paper [13] the authors after examining all possible quantum computing techniques that are based on the principles of quantum mechanics have determined that this technology will help enable computations that are far beyond the reach of traditional computing systems. Qubits that utilise the concepts of quantum mechanics like entanglement and superposition recognise multiple processing states occurring at the same time. Models like Quantum dot Cellular Automata (QCA) allow alternative computing architectures while performing operations on qubits using quantum gates. Different qubit technologies namely superconducting qubits, trapped ions, photonic qubits and topological qubits pose various benefits and hurdles. Various branches of quantum computing include gate-based, analog, measurement-based and quantum annealers which provide advanced processing speeds and miniaturization. Contrary to all the advantages seen, compelling challenges faced by quantum computing include qubit stabilization, error correction, scalability and hardware development. Benchmarking moments in performance analysis include metrics like gate fidelity, quantum volume and Circuit Layer Operations Per Second (CLOPS). Ultimately, to tackle environmental concerns due to energy consumption and e-waste production, quantum computing provides sustainable benefits such as power grids and advancing climate research.

The authors of paper [14] emphasise the immediate call for sustainability in the field of quantum computing, saying the environmental impacts of quantum computing should be premeditated rather than considered for later. The authors further discuss both the pros and cons of quantum computing, stating that while quantum computing provides us with great speed, high computational power and an assorted array of functionality, it also takes a huge toll on the environment. Critical environmental concerns like high energy consumption, rare resource utilization and electrical waste tend to get ignored while paving the way for greater accomplishments in the field of technology. The lack of standardised benchmarks to assess quantum computer's

environmental impact becomes a major challenge. To address and further assess the impact caused by the quantum computing life cycle, i.e. starting from production to disposal, a Carbon aware Quantum Computing (CQC) framework is suggested. The aim of this framework is to calculate the total carbon footprint emitted by quantum computers. This is achieved by considering embodied carbon from hardware production and disposal, operational carbon from energy and water consumption and application-based neutralization of carbon which is nothing, but a contribution made by the quantum computers towards a sustainable environment and thus providing sustainable solutions. While platform fragmentation and the absence of universal performance benchmarks continue to remain a challenge, Life Cycle Analysis (LCA) factors are often used to quantify the aforementioned factors under a unified metric.

This paper also underlines how renewable energy may be a key factor in mitigating the carbon footprint and environmental damage caused by quantum computers. The authors aim to do this by strategically placing data centres in areas that are abundant in sustainable energy sources. In addition to this, the paper also divulges alternatives like green manufacturing, modular designs and recycling of rare earth metals to reduce embodied carbon. Carbon emissions could be substantially counterbalanced by driving quantum computers to its full probable capacity. This may include optimisation of Haber's process for fertilisers, advancements in drug discovery, modelling climate change and improving the efficiency of batteries.

Given the plethora of energy consumed by the ICT sector and the break-neck growth of e-waste, the authors of this paper advocate for a multi-disciplinary collaboration of researchers, educators, leaders of the industry and policymakers to endorse sustainable quantum computing.

The authors of paper [15] initially start the paper by discussing the basics of quantum computing and the principles of quantum mechanics like superposition and entanglement that enables it. The authors argue that while they do not expect quantum computers to replace traditional computers altogether, they believe that the introduction of quantum computers holds immense power and can help solve complex problems, especially in the field of finance. Even with rapid progress, quantum computing still remains in the early stages of development mainly because of the challenges posed by qubit stability and scalability. Quantum computing could also greatly benefit the financial sector by managing risks, optimising portfolios and faster settlement of payments along with macroeconomic modelling. Some experimental results have even showcased promising and exponential computational speed compared to classical or supercomputers. This will enable tasks like VaR calculations for 1-million asset portfolios that would, on an estimate take a classical computer several hours, to be done in 30 minutes using a quantum computer. However, the

authors also believe that the advantages of quantum computing will only be seen in case of exceptionally large problems. The practicality of quantum computers still remains uncertain because of economic factors like higher cost.

Judging from the security point of view, quantum computers also pose a threat to modern cryptography. Encryption algorithms like RSA and ECC that are of utmost importance in the financial world can be easily cracked using Shor's algorithm run on quantum computers. This thus gives rise to vulnerabilities like Harvest Now, Decrypt Later (HNDL), where even if the attacker cannot decrypt the intercepted information now, they can store it and decrypt it later when quantum computers are more widely and easily available. This vulnerability calls for an equally essential prevention technique called Post Quantum Cryptography (PQC), the goal of which is to develop cryptographic algorithms for classical computers that are quantum-resistant. The paper also suggests that while Quantum Key Distribution (QKD) seems to provide secure communications theoretically, it suffers from scalability and cost-induced challenges. The Bank of International Settlements (BIS) Innovation Hub Eurosystem Centre, Bank of France and Deutsche Bundesbank aim to strengthen the financial framework by investing in Post Quantum Cryptography. The project that looks after this has been named Project Leap. In the end, the authors recommend central banks and financial institutions to ready themselves for quantum computing-induced exploits as being unprepared would lead to inevitable financial losses.

Initially, the author of paper [16] discusses the working of quantum computers and the quantum mechanics principles it is based on. Being an underlying technology for ICCT (Information, Communication and Computing Technology), quantum computing technology often crosses paths with other technologies like artificial intelligence, data analytics, cryptography and even in the communications network. Around the world, top countries like the U.S., China, Canada, and the EU are leading the race with a fair amount of contribution from countries like Australia, Japan, South Korea and Singapore. Advancements in quantum computing will also benefit multiple industries, namely healthcare, finance, manufacturing, logistics and even the environment as a whole. Quantum computing has also given rise to improved findings in drug discovery, risk management, climate modelling, and optimization of the supply chain. Despite the advances, qubit stability, scalability and error correction continue to have a deterrent effect on development.

Additionally, the paper underlines the impact quantum computing has on cryptographic algorithms, causing an alarm for security individuals. To prevent security incidents the development of Post Quantum Cryptography and its ability to run on classical computers has been initiated as they stand quantum resistant. Monumental development in the field of quantum networking, sensing and education

have opened new doors for research opportunities. Scope for advanced robotics, optimised networks, secure communication and possibilities in AI acceleration can be seen when quantum technologies are inculcated into ICCT technologies and analysed using the ABCD framework. In spite of its promising future, developments in quantum computing often face many hindrances for reasons such as hardware limitations and environmental interferences. Hence, even though quantum computing shows a promising future and startups are emerging, large-scale practicality remains a goal for the distant future.

Conclusion

Taking everything into account, it is evident that the quantum computing technology is very close to reforming numerous fields, starting from cryptographic algorithms and machine learning to optimization and material discovery. Even though there has been a substantial amount of progress in Noisy Intermediate-Scale Quantum (NISQ) which unlocked compelling near-term opportunities, there have been challenges to fault-tolerant, large-scale quantum computing such as addressing noise and decoherence. Developing scalability and improving the quantum algorithms to make them more advantageous over classical systems also remains a practical challenge on a large scale because of the unavailability of compatible hardware. They can be easily overcome by forming collaborations within diverse industrial sectors, facilitating multidisciplinary research, and making developments in material science. Hybrid quantum-classical approaches have provided efficient solutions to many challenges, including hardware limitations. With the emerging and ongoing advancements in quantum technologies and their integration into industrial and scientific sectors while reformulating various computational paradigms, it also invokes innovations across disciplines hence paving the way for a quantum-enabled future.

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Face Recognition based attendance taking system for employees

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Abstract

An effective workplace is all about its employees and their participation. To keep a track on employee involvement in the workplace, attendance taking systems have evolved through the years. From manual check-ins to biometric scanning – it has come a long way. To maintain the pace of evolving technologies, "Face-Recognition based attendance taking system" plays an important role. It completely automates the attendance recording by making use of the advanced libraries of Python 3.12.4. Dlib, Face-recognition, OpenCV, Openpyxl are the responsible libraries for this task. The working principle of this system works in few steps. It utilizes a webcam to capture the facial structure. The database stores pre-recorded pictures of the employees in various angles to make the database more efficient. Then it compares the captured image to those of the database. If a match is found, the data is then linked to an Excel file to keep track of the attendance. Factors like employee name and time of arrival are main components of that file. The system minimizes human intervention, reduces errors, and makes manipulation infeasible. It represents a strong alternative to traditional methods. Nevertheless, it requires sufficiently strong lights to perform accurate facial detection and operates best in a Wi-Fi-enabled environment. Thus, automation of the attendance process brings innumerable benefits like increasing efficiency, data accuracy, hence enhanced productivity. It becomes an indispensable tool in today's work environment.

Keywords: Face-recognition, OpenCV, Haar Cascade Classifier, LBP Classifiers, Advantages of Face-recognition system.

Introduction

Since the introduction of Industry 4.0 (I4) in 2011 at the Hannover Fair in Germany, automation and machine learning (ML) have piqued the interest of researchers to apply them to industry, agriculture, and other services. This field forms an important part of modern business and research. ML can improve computing performance in processes pertaining to a single factory or system, a chain of factories, or multi-systems used in any organization. I4 will benefit human society when it synergizes artificial intelligence (AI) with automation in production. [1]

Attendance tracking has evolved significantly over the years, from manual sign-in sheets to biometric systems such as fingerprint scanners and facial recognition. Traditional methods, such as manual attendance registers or card-based systems, are time-consuming, prone to errors, and susceptible to manipulation (e.g., proxy attendance). In contrast, biometric systems offer a more secure and efficient way to track attendance. Among biometric technologies, facial recognition has gained prominence due to its non-intrusive nature and high accuracy.

Facial recognition systems analyse unique facial features to identify individuals, making them ideal for applications such as security, access control, and attendance management. Python, with its extensive libraries and ease of use, has become the language of choice for developing facial recognition systems. Libraries such as OpenCV, Dlib, and Face-recognition provide powerful tools for face detection, feature extraction, and matching, enabling developers to build robust and scalable attendance systems.

Problem Statement:

Many organizations still rely on outdated attendance systems that are inefficient, inaccurate, and vulnerable to manipulation. Manual systems are slow and prone to errors, while card-based systems can be cheated or suffer from issues such as lost or misplaced cards. These limitations negatively impact productivity, compliance, and organizational effectiveness.

To address these challenges, there is a growing need for an automated attendance system that is secure, accurate, and efficient. A face recognition-based attendance system offers a modern solution by leveraging facial biometrics to identify employees and record their attendance automatically. Built using Python, this system eliminates the need for manual intervention, reduces errors, and provides a tamper-proof record of attendance.

Scope of the system:

Face detection is a type of identification. When we see any person face, then we will get information like gender and age, etc. Face detection is used in applications such as human-machine interaction, gender classification, surveillance system, bio-metrics, etc., it is very difficult to detect the face. [2]. The proposed system is designed to automate attendance tracking using facial recognition technology. Its key features include:

1. Automatic Attendance Management: Eliminates human errors and reduces the time required for check-ins and check-outs.

2. Accuracy and Reliability: Compares facial features to identify employees, reducing the possibility of proxies or manipulation.

3. Scalability: Suitable for use in corporate offices, schools, factories, and government buildings.

4. Real-Time Recording: Records attendance in real-time, providing up-to-date information on employee presence.

5. Integration with Other Systems: Can be integrated with payroll systems to automate salary processing based on attendance data.

6. Security and Privacy: Encrypts facial data to ensure compliance with privacy regulations.

Core Content

Overview of the system:

The face recognition-based attendance system operates in the following steps:

1. Employee Registration: Employees register by providing their facial data and personal details (e.g., name, employee ID). Multiple images are captured from different angles to ensure robust recognition.

2. Facial Data Encoding: The system extracts unique facial features (e.g., distance between eyes, nose, and mouth) and stores them as embeddings in a database.

3. Attendance Recording: When an employee arrives, the system captures their live image via a webcam, compares it with the stored embeddings, and logs their attendance in real-time.

4. Data Storage: Attendance data is recorded in an Excel file, which can be accessed by employers for reporting and analysis.

Face Detection Techniques

The system relies on face detection algorithms to identify human faces in images. Two primary techniques are discussed:

Haar Cascade Classifier:

The Haar Cascade Classifier is a machine learning-based approach that uses Haar-like features to detect faces. It works by analysing patterns of intensity differences in images and applying a cascade of classifiers to discard non-face regions. While fast and efficient, the Haar Cascade Classifier is sensitive to variations in lighting, pose, and scale.

Paul Viola and Michael Jones proposed Haar Cascade Algorithm, which is productively used for Object Detection. This Algorithm is based on a Machine Learning approach in which lots of images are used, whether positive or negative, to train the classifier.

- **Positive Images:** Positive Images are a type of image that we want our classifier to identify.

- **Negative Images:** Negative Images are a type of image that contains something else, i.e., it does not contain the objects we want to detect. [3]

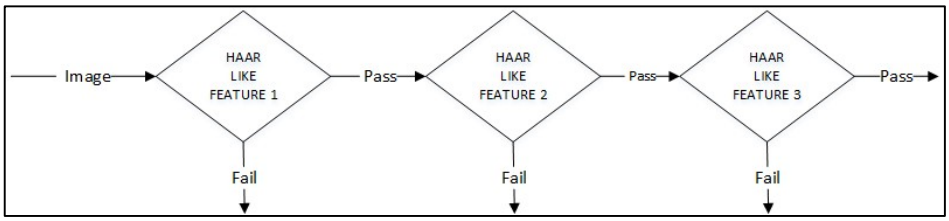


Fig 1: Haar Cascade Classifier flowchart [4]

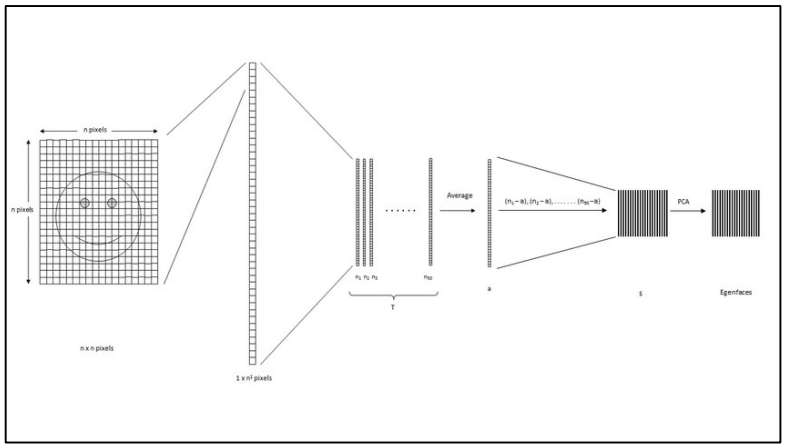


Fig 2: Pixels of the image are reordered to perform calculations for Eigenface [4]

Local Binary Patterns (LBP) Classifier: The LBP Classifier is a texture-based method that detects faces by analyzing local texture patterns. It is robust to changes in lighting but struggles with noise and pose variations. Both techniques are implemented using the OpenCV library.

LBP Features: For each pixel in the image, LBP compares the intensity of the center pixel with its neighboring pixels (typically an 8-pixel neighborhood).

- If a neighboring pixel's intensity is greater than or equal to the center pixel, it is assigned a value of 1; otherwise, it is 0.
- The binary values are concatenated to form an 8-bit binary number, which is then converted to a decimal value (LBP value).

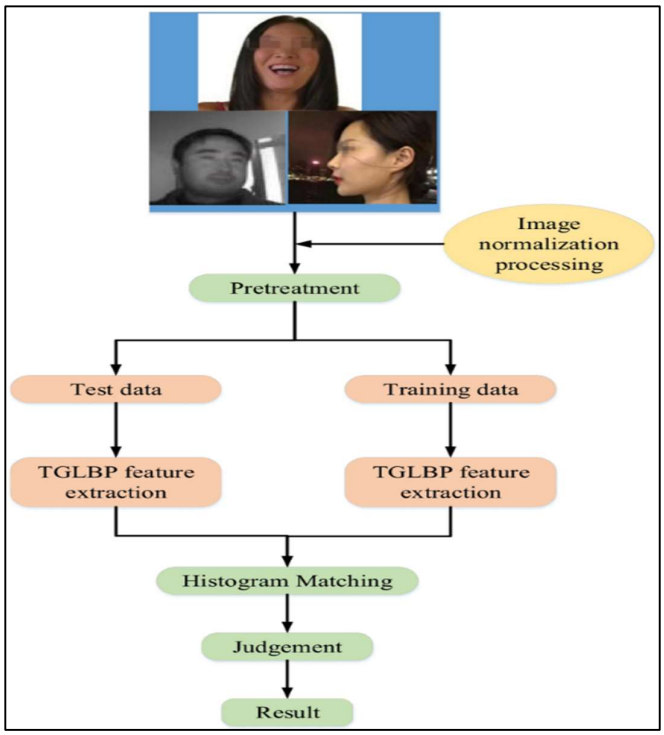


Fig 3: LBP Algorithm flowchart [5]

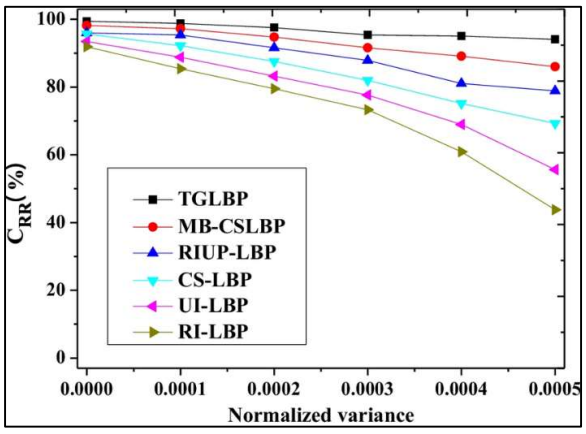


Fig 4: Noise addition experiment curves of algorithms on the CAS-PEAL background set [5]

Working Mechanism

The system works in three major steps. All the steps are correlated to give the desired output of the attendance system. The steps are:

1. Database set up – The database is set by loading the existing photographs of individual employees.

2. Face recognition – The employee is required to stand in front of the image capturing device/camera. The system will capture the image and compare it

with the existing images in the database to trace the similarity in the Haar like features.

3. Logging Attendance – The date and time of attendance is logged in a csv (comma separated values) format datafile for further retrieval and analysis.

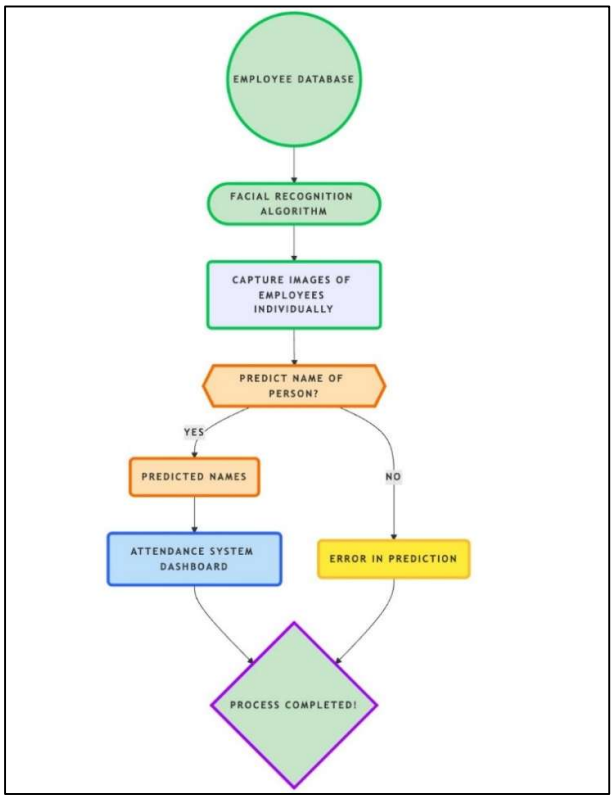


Fig 5: Flowchart of working mechanism of the project

Technological Framework

Main Back-end Language: Python 3.12.4

Python is a high-level general purpose programming language:

- Because code is automatically compiled to byte code and executed, Python is suitable for use as a scripting language, Web application implementation language, etc.
- Because Python can be extended in C and C++, Python can provide the speed needed for even compute intensive tasks.
- Because of its strong structuring constructs (nested code blocks, functions, classes, modules, and packages) and its consistent use of objects and object-

oriented programming, Python enables us to write clear, logical applications for small and large tasks. [6]

With all these features in hand, Python 3.12.4 provides a wide variety of libraries to work with. Hence, a complex program like Face recognition becomes much easier for the robust features of Python.

Corresponding Front-end Languages: HTML, CSS

HTML is a Markup Language. It is used in the project to build a simple yet efficient user interface.

CSS is a Stylesheet based Language. It provided the graphic user interactivity in the system.

IDE: Visual Studio Code

A versatile and well managed IDE is provided by the Visual Studio Code. It's memory efficient approach makes it easier to organize all the languages and framework into one.

Libraries in use:

Python Libraries provide a wide set of actions depending on specific tasks. It is very helpful in data encapsulation and providing abstraction to the author. The libraries which are used in the project are:

i. OpenCV-python
ii. Cmake
iii. Dlib
iv. Face-recognition
v. Face-recognition-models
vi. Pandas
vii. Numpy 1.26.4
viii. Flask
ix. setuptools

OpenCV Library in Python

OpenCV (Open Source Computer Vision Library) is a powerful open-source library designed for computer vision and image processing tasks. It provides tools to analyze, manipulate, and process images and videos, making it essential for applications like object detection, face recognition, and augmented reality.

OpenCV was started at Intel in 1999 by Gary Bradski for the purposes of accelerating research in and commercial applications of computer vision in the world and, for Intel,

creating a demand for ever more powerful computers by such applications. Vadim Pisarevsky joined Gary to manage Intel's Russian software OpenCV team. Over time the OpenCV team moved on to other companies and other Research. Several of the original team eventually ended up working in robotics and found their way to Willow Garage. In 2008, Willow Garage saw the need to rapidly advance robotic perception capabilities in an open way that leverages the entire research and commercial community and began actively supporting OpenCV, with Gary and Vadim once again leading the effort. [7]

The driving force behind the whole program is the OpenCV library. It uses cascading technique to implement the face recognition using Haar Cascade Algorithm. It analyses the images by their HSV components, where H stands for Hue, S stands for Saturation and V stands for Value. In OpenCV, the Hue component ranges from 0 to 179 as it takes the image input as a 8 bit unsigned array.

```
rgb_small_frame = cv2.cvtColor(small_frame , cv2.COLOR_BGR2RGB)
```

In this code snippet, the cv2.cvtColor() command changes the color space from RGB (Red-Green-Blue) to HSV color space. As OpenCV takes an image input in the BGR (Blue-Green-Red) color mode by default, the mode is changed to RGB using cv2.COLOR_BGR2RGB command. Thus, the further analysis of Haar-like features is done in the system.

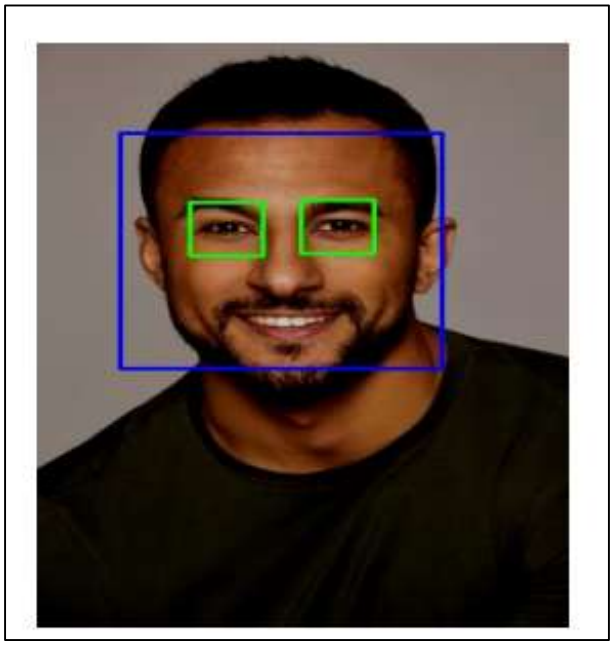


Fig 6: Considering the single face object (Singh et al.)

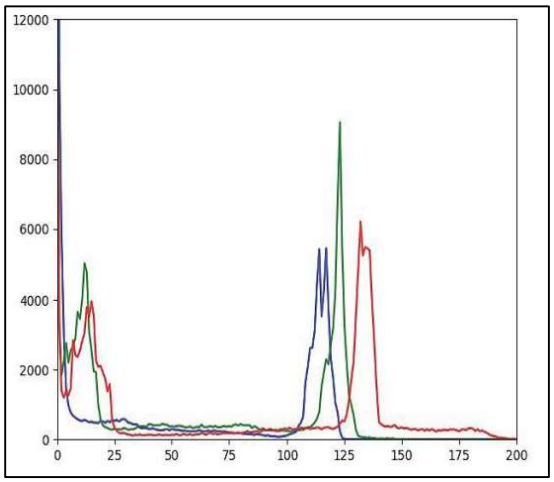


Fig 7: Histogram of the RGB graph for the image (Singh et al.)

Implementation

1. Folder Creation: A dedicated folder for the project is created in VSCode interface. It will have the employee images as contents.

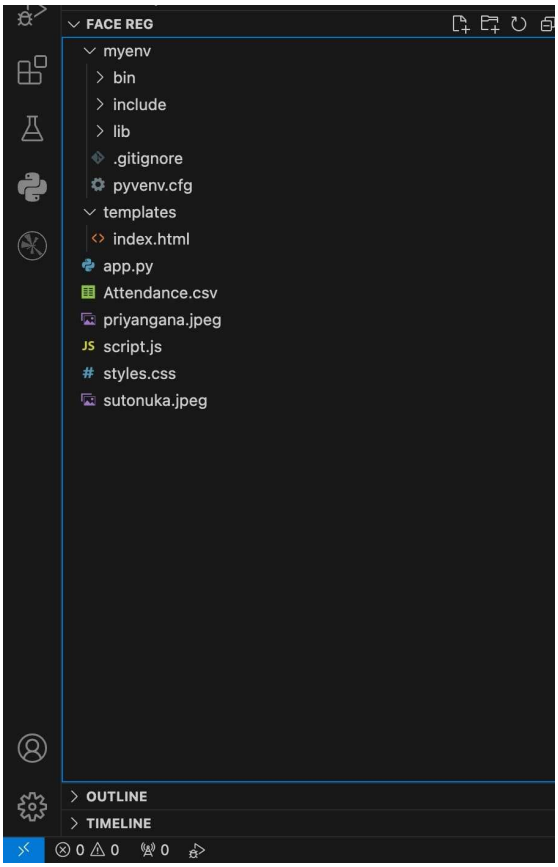


Fig 8: Main folder creation

2. Creation of virtual environment: A virtual environment named ‘myenv’ is created for optimized library installation. Activate the environment using terminal of VSCode.

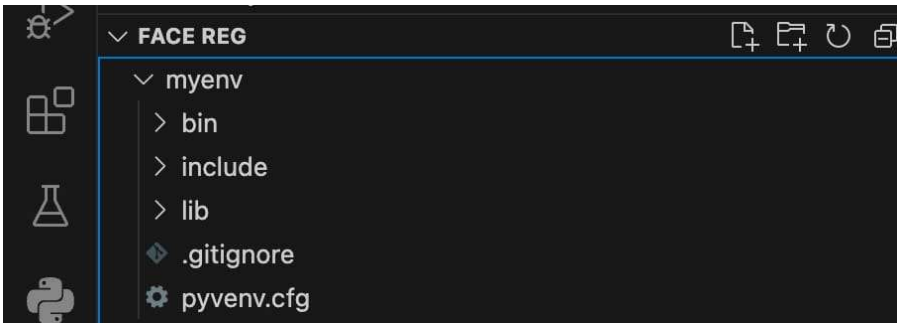


fig 9: Virtual environment is created named ‘myenv’

3. Install the libraries: The ‘pip install’ command is used to install all the libraries. After successful installation ‘pip list’ command will view the following list of installed libraries:

Package	Version
blinker	1.9.0
click	8.1.8
cmake	3.31.4
dlib	19.24.2
et_xmlfile	2.0.0
face-recognition	1.3.0
face_recognition_models	0.3.0
Flask	3.1.0
itsdangerous	2.2.0
Jinja2	3.1.5
MarkupSafe	3.0.2
numpy	1.26.4
opencv-python	4.10.0.84
openpyxl	3.1.5
pandas	2.2.3
pillow	11.1.0
pip	24.3.1
python-dateutil	2.9.0.post0
pytz	2024.2
setuptools	75.8.0
six	1.17.0
tzdata	2024.2
Werkzeug	3.1.3

fig 10: List of libraries installed for the project

4. Results: After compiling, debugging and running the program the terminal will display to redirect to the mentioned port using a web browser.

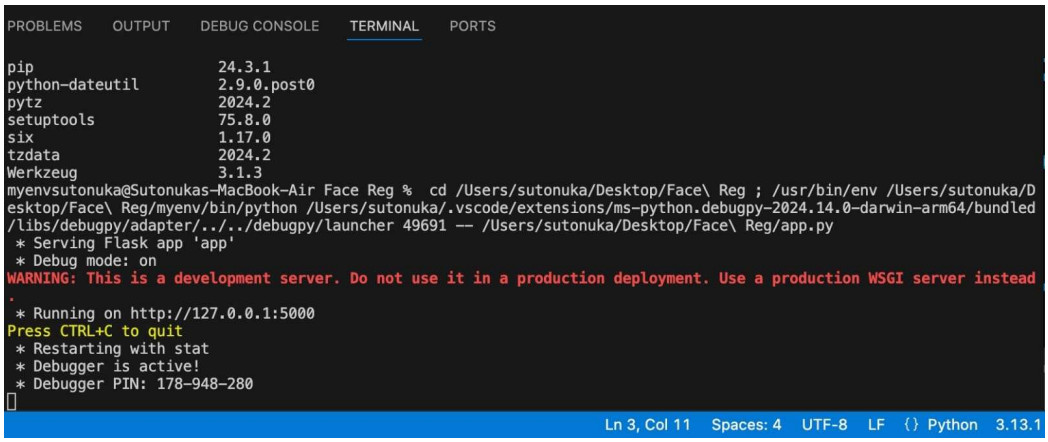
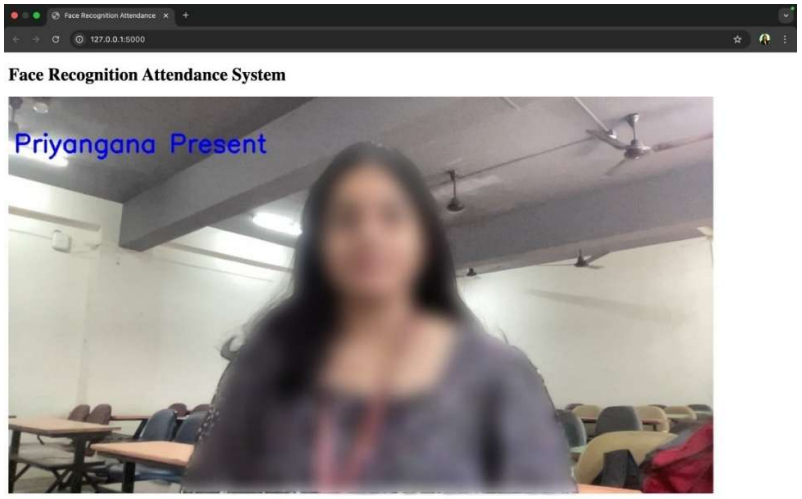


Fig 11: Terminal displaying to redirect to the given web address

After redirecting to the web page, the attendance is taken by the face -recognition model.



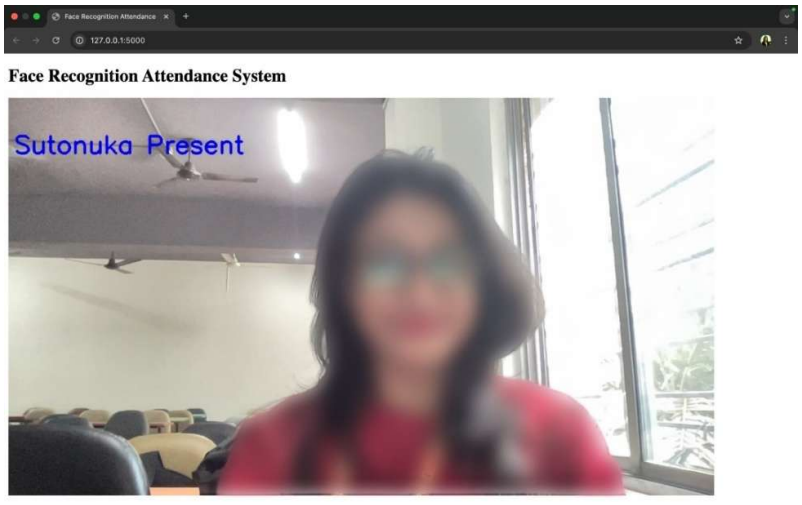


Fig 12 & 13: Face-recognition model

Finally, the attendance is saved in a csv file named ‘attendance.csv’ by the comma separated values.

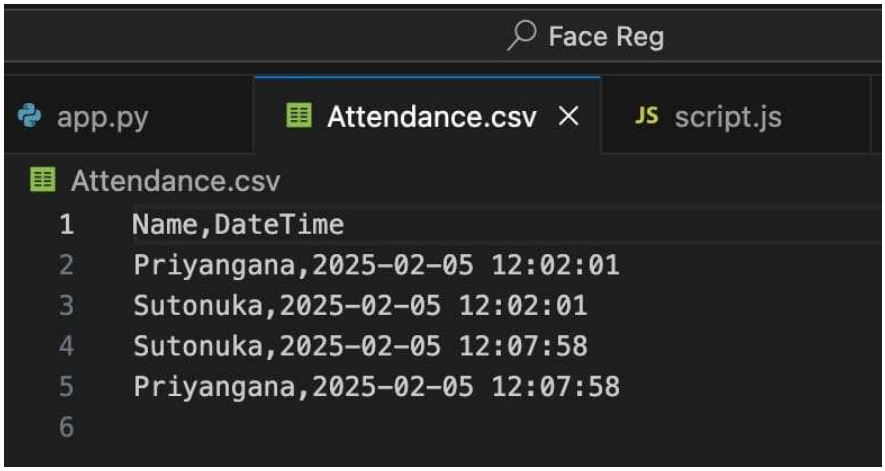


Fig 14: Attendance logged in csv format

Challenges:

- Lighting Conditions: Effective detection requires adequate lighting.
- Hardware Requirements: Requires a webcam and sufficient processing power.
- Connectivity: Operates effectively only within Wi-Fi-enabled areas.
- Technical dependency: The system may collapse if there is any technical malfunction, which may lead to potential data loss.

Implementation Guidelines

- **Hardware Requirements:**
  - Laptop/PC with i3 processor or higher.
  - 4 GB RAM or higher, 100 GB ROM or higher and a functional webcam.
- **Software Requirements:**
  - Python 3.12.4.
  - HTML
  - CSS
  - Visual Studio Code or preferred IDE.
- **Setup:**
  - Create a dedicated folder for the project and a virtual environment within the IDE.
  - Install necessary libraries like OpenCV, Dlib, Openpyxl and Face-recognition.
  - Set up database by including the pictures.

- Configure the system for real-time attendance marking.

Conclusion:

In the era of Industry 4.0, the focus on automation is relevant in every aspect of workplace and organization. Based on face recognition technology, Face Recognition System works out a comprehensive and progressive solution for addressing employee attendance.[8] Due to the factors of enhanced accuracy and reduced human intervention with improved data security and reliability, it is a better solution compared to other conventional methods of attendance. Despite the limitations such as lighting condition and dependency on the hardware, the advantages exceed these problems a lot, which makes this method a perfect solution for the modern organization, which is searching for an effective way to manage the attendance problem.

Future Scope:

- Connecting the system with Cloud Environment will help with Data Designing and organizing. Which in turn will ease the process of Data retrieval and analysis to take future decisions. A dedicated database will also help in data privacy and security.
- In various highly confidential organizations, face detection can be merged with other biometric prompts like fingerprints, will help to establish multi-facto authentication system to ensure data integrity.
- Using Face detection system with a proper database in workplace will help to trace out employee traits by analysing their attendance performance, which will help in HRM (Human Resource Management).
- Convolutional Neural Network (CNN) helps in image analysis. Application of Face recognition system may help in detailed facial structure analysis when it comes to restrained conditions like lighting or angle.[9]
- Real-time data processing feature of the system will help in building smart office environment by implementation of IoT (Internet of Things).

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GESTURA: A real time Gesture to Speech Interpreter

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Abstract

This work presents a novel approach to sign language translation by integrating Electromyography (EMG) signals with Natural Language Processing (NLP) to enhance contextual understanding. The primary challenge addressed is the communication barrier faced by individuals who are deaf or hard of hearing, particularly the limited ability of non-sign language users to comprehend sign language. Current systems often require both parties to understand sign language, which is not always feasible. The proposed solution involves the development of a real-time machine learning model, portable device that translates hand gestures into text, thereby facilitating clear communication. The literature survey highlights the reliability of EMG-based systems in capturing muscle activity, while also acknowledging their limitations, such as signal noise and the need for precise Gesture recognition. By incorporating NLP, the system aims to improve the contextual accuracy of translations, overcoming the shortcomings of existing gesture recognition systems. The expected outcome is a robust assistive communication tool that significantly enhances interaction for individuals with communication disorders, ultimately contributing to the field of assistive technology.

Keywords — Sign language translation, Electromyography (EMG), Natural Language Processing (NLP), Gesture recognition, Machine learning

Introduction

In today's digital age, human-computer interaction (HCI) plays a pivotal role in shaping user experiences across various domains, from virtual reality gaming to assistive technologies for individuals with disabilities. Traditional input methods such as keyboards and mice have limitations in terms of intuitiveness and accessibility. As such, there is a growing demand for more natural and immersive interfaces that can bridge the gap between humans and machines seamlessly.

These gloves are designed to capture intricate hand movements and translate them into actionable commands, revolutionizing the way we interact with computers and digital environments.

The objectives for this work is to accurately detect finger movements, map these specific movements to corresponding text, and develop a machine learning model capable of classifying input gestures with precision. Additionally, the work aims to convert the generated text into voice signals to enhance accessibility. The overarching goal is to create a portable, cost-effective, and user-friendly system that can perform real-time sign language translation, making it both practical and efficient for users who need instantaneous communication assistance.

Literature Review

Sr. No.	Title	Publisher	Year	Methodology	Conclusion
1	Sign Language Interpreter Using Machine Learning	IEEE	2024	Combined wearable flex sensors and a microcontroller to collect gesture data; implemented supervised machine learning to classify gestures into corresponding text.	Showcased the feasibility of real-time gesture interpretation, improving accessibility for individuals unfamiliar with sign language.
2	Real-time Sign Language Recognition using Machine Learning and Neural Network	IEEE	2023	Used neural networks to process input signals from multiple sensors, including accelerometers and gyroscopes, and trained the model with labeled gesture data.	Provided a scalable and efficient solution for dynamic gesture recognition, applicable in wearable technology.
3	Sign Language Prediction using Machine Learning Techniques: A Review	IEEE	2023	Surveyed various ML techniques such as SVM, decision trees, and neural networks, comparing their performance in gesture recognition across different datasets.	Identified challenges in data availability and emphasized the importance of robust ML models to ensure diverse and inclusive recognition systems.
4	Sign Language Recognition using Deep Learning	IEEE	2024	Developed a deep learning pipeline utilizing CNNs to extract spatial and temporal features from gesture images or signal data	Improved recognition accuracy and robustness, demonstrating potential for deployment in real-world scenarios.
5	EMG-Based Gesture Recognition for Sign	IEEE	2022	Collected EMG data using wearable sensors; preprocessed signals to reduce noise and used machine learning for classification	Established reliable methods for using EMG signals to classify gestures,

	Language Interpretation				suitable for assistive technologies.
6	Accelerometer -Based Gesture Classification in Wearable Devices	IEEE	2021	Implemented a wearable device with sensors mounted on specific positions to precisely measure the gestures.	Demonstrated precise motion tracking, laying the foundation for enhanced gesture-based communication devices.

Table 1.1 Review of the previous works

S. Anthoniraj et al. [1] discussed the ability of EMG signals to capture real-time gesture patterns by assessing skeletal muscle activity. In the proposed model, hand gesture recognition accuracy was achieved at high levels in real-time applications. Signal variability and noise during such applications posed a problem, thereby requiring improved signal processing and machine learning techniques to ensure higher consistency.

R. Matlani et al. [2] conducted a study on vision-based systems for sign language recognition, based on image recognition techniques for detecting hand and body gestures. Though non-invasive, they suffer from several drawbacks, which include poor performance in low light conditions, privacy issues, and inability to capture minimal movement. The authors suggested the use of EMG-based systems instead.

D. Aggarwal et al. [3] discussed the portability of EMG-based systems for assistive communication devices, demonstrating their effectiveness in capturing sign language gestures for daily use. However, the lack of sensor positioning and inconsistency of muscle signals restrict their use and there is a need for developing adaptive sensors and strong training algorithms.

D. Kothadiya et al. [4] made use of supervised learning models applied to EMG data improve the accuracy of gesture recognition. However, the contextual unawareness confines their system to interpreting only complex or nuanced gestures; hence, they suggest adding Natural Language Processing to understand the gestures in a wider conversational perspective.

S.K. Singh et al. [5] had focused on EMG-based sign language translation wherein the EMG signals are mapped to particular signs. Even though it has demonstrated that EMG can be useful in sign language translation, some issues are still encountered, such as contextual accuracy and ambiguity resolution. They, too, recommended NLP integration to improve the quality of translations.

Finally, T. Marasović et al. [6] emphasized the importance of contextual awareness in improving gesture recognition accuracy. By integrating NLP techniques with EMG signals, they proposed a system incorporating context mapping, which significantly reduced errors and enhanced performance, particularly during complex conversations.

This integration highlights the potential for creating more accurate and meaningful gesture-based communication systems.

I. Proposed System

The proposed system consists of four key components:

1. Gesture Recognition Module
   - Captures real-time hand movements using EMG sensors and accelerometers.
   - Maps gestures to individual words using a trained ML model.
2. Context-Aware Text Generation Module (T5-Base)
   - Takes the predicted words and paraphrases them into coherent and grammatically correct sentences.
   - Utilizes a Persistent KV Cache Mechanism to retain context across multiple calls.
3. Persistent KV Cache Mechanism *(Proposed Innovation)*
   - Stores the transformer's Key-Value (KV) cache in an external memory buffer (RAM or Flash).
   - Updates this cache dynamically to reuse past context for real-time sentence formation.
4. Text-to-Speech (TTS) Conversion Module
   - Converts the final grammatically corrected sentence into speech.

Methodology

The proposed system follows a structured pipeline for real-time gesture recognition and speech synthesis, integrating hardware-based signal acquisition, machine learning-driven classification, and natural language processing (NLP) for grammatically correct speech output.

1. Hardware Design and Data Acquisition
   The system is built around a custom-designed wearable device equipped with accelerometers and an ESP32 for real-time motion and electromyography (EMG) signal acquisition. The device captures:
   - EMG signals (2 channels per hand)
   - Accelerometer data (6 dimensions per hand)

   This results in a 16-dimensional feature space (8 per hand) that is transmitted via a wired connection to a Raspberry Pi for further processing.

2. Data Processing and Preprocessing Pipeline
   Once received by the Raspberry Pi, the raw data undergoes several preprocessing steps:
   - Noise filtering using bandpass filtering to remove unwanted EMG artifacts
   - Normalization & feature scaling to maintain consistency
   - Dimensionality reduction (if needed) to optimize computational efficiency.

3. Gesture Recognition Using Hybrid Machine Learning Model

The processed 16-dimensional data is then fed into a gesture classification model, which consists of:

- Artificial Neural Network (ANN) trained on the 16D feature set for initial gesture detection.
- Ensemble Learning Approach combining ANN with strong classifiers (Random Forest, Gradient Boosting, SVM) to enhance accuracy and robustness.

Once a gesture is detected, it is mapped to its corresponding text representation.

4. Context-Aware Paraphrasing for Indian Sign Language (ISL)
   Since Indian Sign Language (ISL) sentences often follow a syntactically different structure (e.g., "TONIGHT HOME LATE NOT." instead of "Don't be late coming home tonight."), a custom-trained T5 paraphraser is introduced to generate grammatically correct text. To maintain linguistic coherence, we implement a Persistent Context-Aware KV Cache Mechanism, allowing the paraphraser to retain context across multiple text generations:

   - Persistent KV Cache for Long-Term Context

   Instead of discarding the KV cache after each generation, past key-value states are stored in structured external memory (RAM, NVMe SSD, or Flash storage) for retrieval.

   - Modifying the T5 Generation Process

   The generate() function is modified to accept an external past_key_values parameter.

   When a new word is detected, the system retrieves previous KV states and injects them into the next generate() call, ensuring grammatical and contextual continuity.

   - Efficient KV Storage

   Circular buffer in RAM stores recent KV cache for fast retrieval.

   Periodic Flash memory storage is used for longer retention, ensuring a balance between performance and memory constraints.

   - Rolling Context Window

   Instead of indefinitely storing all tokens, a sliding window mechanism keeps only N past tokens, dynamically pruning older, irrelevant context to prevent excessive memory usage.

5. Emotion-Aware Speech Synthesis
   Simultaneously, a sentiment analysis model evaluates the emotional tone of the paraphrased sentence. Emotional tagging is applied to different parts of the sentence, which then influences the Mini-Parler TTS module to generate human-like speech with appropriate tone, pitch, and cadence.

6. Real-Time Feedback Loop for Adaptive Learning

To improve accuracy over time, the system incorporates a user feedback mechanism, enabling corrections that fine-tune both:

- The gesture recognition model (retraining with new samples)
- The paraphraser and speech synthesis module (adjusting linguistic structures and sentiment mapping)

This ensures continuous adaptation and refinement, making the system more precise and context-aware over repeated usage.

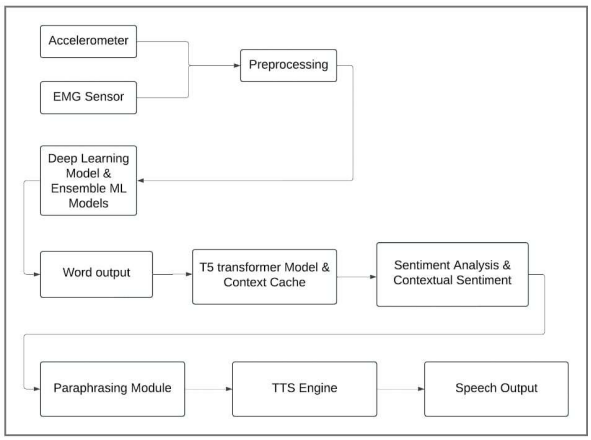

Fig. 1. Block diagram for gesture interpretation and speech generation

Implementation

The implementation of the proposed gesture interpretation system involves a seamless integration of hardware and software components, ensuring real-time processing and accurate translation of hand gestures into meaningful speech. The system is built on a Raspberry Pi platform, where necessary libraries such as Adafruit ADS1x15 for analog EMG signal acquisition, MPU6050 for accelerometer data, and TensorFlow Lite for efficient machine learning inference are installed.

The first step is enabling I²C communication, which facilitates data transfer between sensors and the microcontroller. The EMG sensor and accelerometer are then connected to capture muscle activity and hand movements, respectively. Once the sensors are initialized, signal acquisition begins, where raw data undergoes preprocessing, including noise filtering using band-pass and low-pass filters and normalization for consistency. The preprocessed signals are then segmented using a sliding window approach to create manageable data chunks, which are subsequently used for feature extraction.

Feature extraction plays a crucial role in gesture recognition, where time-domain and frequency-domain features such as root mean square (RMS), variance, and power spectral density are derived from the EMG and accelerometer data. A deep learning

model, primarily an artificial neural network (ANN), is trained alongside an ensemble classifier, incorporating techniques such as Random Forest, to enhance recognition accuracy.

The classified gestures are then mapped to predefined words and transmitted to the next processing stage, where a modified T5-based transformer model performs grammar correction. This transformer model receives words sequentially, updates a context buffer, and dynamically adjusts sentence structure to maintain grammatical coherence and context relevance. The model refines tenses, adds missing words, and restructures the sentence based on an autoregressive approach, ensuring a natural flow of language.

Simultaneously, a sentiment analysis module processes the evolving sentence, extracting emotional cues using a pre-trained sentiment classifier. This module assigns a sentiment score—positive, neutral, or negative—by analyzing embeddings from the grammar correction system. The sentiment score is then passed to the text-to-speech (TTS) engine, which employs an advanced speech synthesis model such as Tacotron 2 or FastSpeech to generate emotion-aware speech output. Based on the sentiment score, the TTS engine modulates tone, pitch, and speed to reflect the user's emotional intent, ensuring an expressive and natural speech synthesis.

Finally, the system incorporates a feedback loop, allowing users to validate and refine gesture recognition accuracy over time. User-specific gestures are incrementally learned, optimizing the model's adaptability and robustness. This comprehensive implementation strategy ensures that the system operates efficiently, providing a real-time, user-friendly solution for converting hand gestures into grammatically and contextually accurate speech.

4.1 Data Flow and Processing Pipeline

1. Gesture Prediction → Initial Word Formation
   - The system predicts words from gestures using EMG sensor input and a trained classification model.
2. Context-Aware Paraphrasing (T5 with Persistent KV Cache)
   - The predicted words are tokenized and fed into the T5 model for paraphrasing.
   - The model generates grammatically correct text using a stored KV cache from previous interactions.
3. KV Cache Storage and Retrieval
   - The KV cache from previous generate() calls is stored in an external buffer.
   - When a new word arrives, the system retrieves and injects stored KV pairs into the next generation call.

4. Text-to-Speech Conversion
    - The final corrected output is converted into speech using Parler-TTS/Coqui-TTS.

4.2 Key Technical Implementations

Modifying the T5 Generation Process to Accept:

1. External KV Cache
    - Modify the generate() function to accept an external past_key_values parameter.
    - Before running generate(), retrieve stored KV cache from memory and inject it into the new input sequence.
2. Efficient KV Storage Mechanism
    - Implement a circular buffer in RAM to store recent KV cache for fast retrieval.
    - For longer retention, periodically store and retrieve KV cache from NVMe SSD or Flash memory.
3. Rolling Context Window
    - Instead of storing all tokens indefinitely, keep a sliding window of past N tokens to avoid excessive memory usage.
    - Ensure old, irrelevant context is pruned dynamically.
4. Optimizing Cache for Low Latency
    - KV cache retrieval should be non-blocking to maintain real-time processing speed. Using CUDA pinned memory for fast GPU access reduces overhead.

Results and Analysis

Feature	**Our Product (EMG+Accelerometer)**	**SignaLoud (Glove-Based)**
Sensor Technology	Uses EMG sensors to capture muscle activity and MPU6050 accelerometers for motion tracking	Uses flex sensors for finger bending and IMUs for motion detection
Wearable Form Factor	Fabric-based bands with Velcro straps for easy attachment on forearm	Gloves that cover the entire hand, possibly restricting natural movement
Communication Medium	Uses ESP32 & Raspberry Pi wired communication like I2C	Uses Bluetooth to transmit data to a smartphone
Data Processing	Uses Machine Learning (ML) model to	Uses predefined sign-to-text

	predict gestures	conversion
Context Understanding	Supports NLP-based translation for better context recognition	No NLP integration, works with a predefined sign-to-speech mapping
Accuracy	Higher accuracy due to muscle activation + movement tracking	Lower accuracy as flex sensors only detect finger bending
Language Flexibility	Can be customized for different sign languages & dialects	Limited to predefined sign language database
Application Scope	Can be used for assistive communication, prosthetics, and smart wearables	Mainly for basic sign-to-text conversion
Latency in Data Transmission	High speed compared to Bluetooth and minimum data loss	Higher latency as Bluetooth communication relies on external devices
Power Efficiency	Optimized power consumption with Raspberry Pi and ESP32 sleep modes	Consumes more power due to continuous Bluetooth transmission
User Comfort	Lightweight & flexible, does not restrict hand movements	Can be restrictive, especially during prolonged use

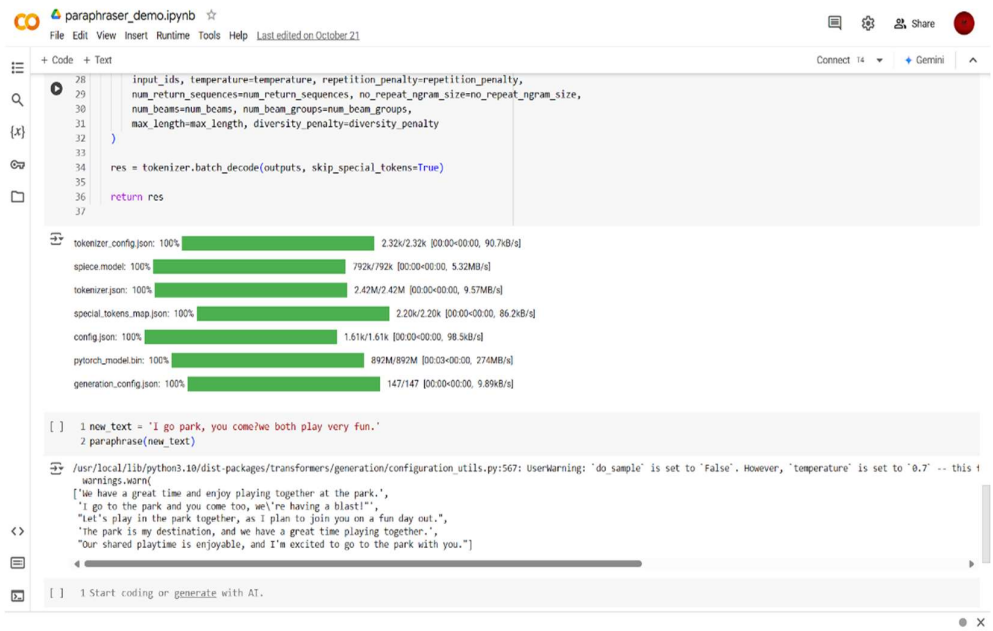

Fig. 2. T5 Model Paraphrasing Output Grammar correction and paraphrasing:

1. A transformer model (humarin / chatgpt_paraphraser_on_T5_base) was chosen because of its fast sequence to sequence transfer with contextual understanding, making it reliable for emotion matching required for speech generation.
2. Below are some demo results, not much refined, as the data is going to be huge.
3. You can see that the above model, helps adding helping verbs and paraphrases the input text.

ANN:

A deep neural network was trained with some hyperparameter tuning namely SGD, RMSProp, Adam as optimizer, etcetera.

```
#SGD #RMSprop #Adam #Adadelta #Adagrad ##Adamax ###Nadam #Ftrl
opt = optimizers.Nadam(lr=1e-3)
model.compile(optimizer = opt,
              loss = "categorical_crossentropy",
              metrics = ["accuracy"])

model.summary()
```

```
Model: "functional_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_2 (InputLayer)         [(None, 8)]               0
_________________________________________________________________
functional_3 (Functional)    (None, 32)                610016
_________________________________________________________________
dense_10 (Dense)             (None, 8)                 264
=================================================================
Total params: 610,280
Trainable params: 610,280
Non-trainable params: 0
_________________________________________________________________
```

Fig. 3. ANN model summary of parameters

The Image below represents the accuracy and loss of Training and Validation data, which resulted in

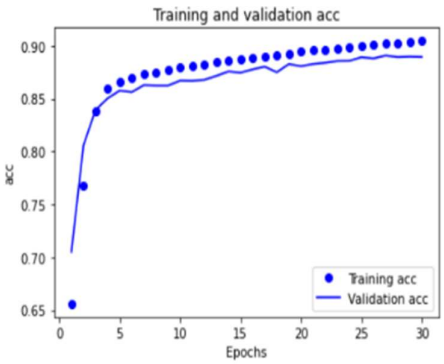

Fig. 4. Training (28.76%) & validation loss (37.28%)

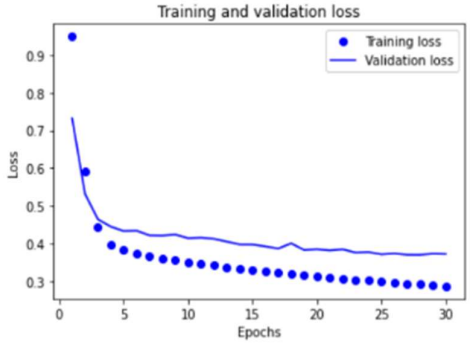

Fig. 6.3.4 Training (90.4%) & validation accuracy (88.94%)

Conclusion

Communication between sign language users and nonusers is greatly improved by the Sign Language Interpreter system, which offers an efficient way to convert sign language motions into text. This system achieves high precision in gesture identification by precisely capturing and interpreting hand gestures using EMG signals. Context aware translations, made possible by the incorporation of Natural Language Processing (NLP), produce output that is both correct and pertinent to the conversational context. The system is a useful, accessible tool that lowers communication barriers and promotes inclusion for people with speech and hearing impairments because of its real-time processing and user- friendly design. This research proposes a Persistent KV Cache Mechanism for real-time gesture-to-speech conversion, allowing context-aware text generation using the T5 model. By retaining past context across multiple generate() calls, the system ensures grammatical correctness and fluency in generated speech.

Future work includes:

1. Exploring Retrieval-Augmented Generation (RAG) to dynamically fetch contextual information.
2. Optimizing cache storage for minimal latency with hardware acceleration.
3. Evaluating on different transformer architectures like GPT-based models.

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Satisfaction and Continued Partnership Intent of the Restaurant partners of Zomato: A Latent Variable Computation Model for Sustainable CRM

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Abstract

Purpose- The food aggregator business in India is a dynamic, fast-growing sector with immense potential for innovation and expansion.This study helps in understanding tier-3 markets in India's digital food industry. This study aims to identify the factors that are responsible for increasing the level of satisfaction vis-à-vis the manifestation of continued partnership intent of restaurant partners and develop a predictive model for various online food aggregators. Thus, it will help the companies to build a better platform to boost restaurant partners' expectations in the long run.

Research Design/Methodology- The study is based on primary data collected from 200 restaurant partners who are operating their food business with the help of different platforms namely Zomato and Swiggy in the Durgapur region. Exploratory Factor Analysis and there after Multiple Linear Regression and Binary Logistic Regression in SPSS 20.0 has been used to explore the relationship between the latent constructs and the dependent variable as Satisfaction Rate and Continued Partnership Intent respectively. The study finds a unique and interesting shift of scale with the predicted satisfaction and hence the manifestation of continued partnership intent getting to be dichotomous and therefore the model was further tested for its robustness using the Confusion Matrix and Machine Learning Performance parameters.

Findings-The study has identified four basic underlying factors affecting restaurant partner's satisfaction namely concern for On-boarding Dynamics, Order Handling Efforts, Customer Relationship Management(CRM) Efforts, Platform Features.

Research limitation/implication- This study was conducted with respondents from the Durgapur region of South Bengal. The study can be extended to other parts of India with more number of respondents and more factors can be unveiled and companies can work upon them effectively.

Keywords: AVE, Composite Reliability, Confusion Matrix, Continued Partnership Intent, Cronbach's Alpha, Fornell-Larcker Criterion, EFA, Logistic Regression, ROC, Satisfaction.

Introduction

Online food aggregation has transformed dining habits of customers all over the world, and India is no exception. Platforms like Zomato and Swiggy, have enabled consumers to browse menus, place orders, and access a wide variety of restaurants from anywhere and at anytime. Despite its urban success, Zomato still faces challenges in tier-3 cities like Durgapur, where consumer behaviour and restaurant needs differ significantly.

The food aggregator business is a booming sector within the food service industry, transforming the way of dinning from a wide range of restaurants and food outlets. A food aggregator connects customers with multiple dining restaurants through an online platform or mobile app. The food aggregation industry has experienced significant growth in recent years, driven by the increasing demand for convenient and accessible food delivery services (Sellappan & Shanmugam, 2021). As a result, understanding the key drivers of restaurant partner satisfaction has become critical for the sustainability and success of these platforms.

One of the primary drivers of restaurant partner satisfaction is the ability of food aggregation platforms to facilitate business model innovation and collaboration. (Chan et al., 2023) Food outlet operators are often faced with the dilemma of whether to collaborate with aggregators or develop their own delivery networks, and the research indicates that the ability to adapt and adjust their business models is crucial for their success. (Chern & Ahmad, 2020) Identifying and understanding the strategic expectations of restaurant partners, such as operational efficiency and synergy, is a critical requirement for establishing a sustainable and mutually beneficial partnership. (Sellappan & Shanmugam, 2021)

Additionally, the importance-performance analysis approach has been identified as a valuable tool for understanding the key factors that drive restaurant partner satisfaction by a plethora of extant literature. Hence recognizing the critical expectations of restaurant partners and assessing the platform's performance efforts in meeting these expectations would be a great strategic score card for the food aggregator platforms.

As this will help them to prioritize areas for improvement and enhance their overall service offering to ensure a sustainable co-existence in the days to come.

Our study, based on the data collected from a random sample of 200 restaurant partners from the City of Durgapur in South Bengal. It attempts to identify the major underlying components or factors that affect the restaurant partners' expectations vis-à-vis their perceptions concerning the aggregator's efforts, which is critical for their manifestation of continued partnership intent with the food aggregator platform.

Research Question

- ✓ What are the factors affecting the restaurant partner's satisfaction and hence their continued Partnership intent with the food aggregator platforms?
- ✓ What is the impact of each of the factors on the restaurant partners' Satisfaction and hence their Continued Partnership Intent?

Method

A: Variables: The study was initialised with a mixed-methods approach, identifying the variables affecting the restaurant partners' expectations and perceptions using in-depth structured interviews of the Zomato officials and review of existing literature. Initially, eighteen (18) variables were listed out (given in table 1 below) to frame a structured questionnaire to be administered to the existing restaurant partners of Zomato in the Durgapur City. The responses were gathered on a 5-point Likert scale.

Sl. No	Statement	SPSS Variable	Type of variable
1	The on boarding process with Zomato was straightforward and easy to understand	Onboarding Process	Ordinal
2	The documentation required during on boarding was clear and concise.	Documentation during onboarding	Ordinal
3	The initial training provided by Zomato was sufficient to help us get started.	Initial Training	Ordinal
4	The commission rates charged by Zomato are reasonable.	Customer support service	Ordinal
5	Zomato's customer support team is responsive and helpful.	Comm. Regarding Updates	Ordinal
6	We find it easy to update our menu and restaurant information on Zomato.	Solution to the Issues	Ordinal
7	The communication from Zomato regarding platform updates is clear and timely.	Platform Operation	Ordinal
8	Zomato provides effective solutions to any issues or challenges we face.	Order management	Ordinal
9	The Zomato platform is user-friendly and easy to navigate.	Update of menus	Ordinal
10	The order management system on the Zomato platform is efficient.	Platform Advantage	Ordinal
11	Zomato helps in attracting new customers to our restaurant.	Attraction to Customers	Ordinal
12	The promotions and marketing campaigns run by Zomato are beneficial for our business.	Promotional Benefits	Ordinal

13	Partnering with Zomato has increased our overall sales.	Commission Rates	Ordinal
14	We are satisfied with the pricing structure for using the Zomato platform.	Pricing Structure	Ordinal
15	The fees associated with Zomato services are clearly communicated	Platform Fees	Ordinal
16	The integration of Zomato with our restaurant's point of sale (POS) system is seamless	POS integration	Ordinal
17	Zomato's technology and tools help improve our restaurant operations.	Technological Advantages	Ordinal
18	We find the analytics and reporting tools provided by Zomato valuable for our business.	Analytical Tools	Ordinal
19	We are satisfied with our overall experience as a Zomato partner.	Sat_1	Ordinal
20	We are so satisfied that we recommend other restaurants to partner with Zomato	Sat_2	Ordinal
21	SATISAFACTION RATES	Computed Average of (Sat_1 & Sat_2)	Scale
22	I would like to continue the partnership with Zomato for the next 5 years	Continued Partnership Intent	Ordinal

Table 1 : List of Variables

B: **Research Design and Tools used:** Responses of 207 restaurant partners were collected all over Durgapur to analyze the factors that affect their satisfaction levels. After cleaning 200 responses were considered. **EFA**, **or Exploratory Factor Analysis**, was used to identify the underlying constructs. The impact of the constructs on the Satisfaction rates of the restaurant partners assessed using the **Multiple Linear Regression**.

The **Binary Logistic Regression** is used to analyse the relationship between the dependent variable manifestation of "Continued Partnership Intent" and the underlying constructs. The study finds a unique and interesting manifestation of continued partnership intent getting to be dichotomous. Thus, multiple regression becomes unsuitable in this case. However, Satisfaction rate, was a continuous variable and has been found to follow a Multiple Linear Regression. Interestingly, Continued Partnership Intent is translated to a rather dichotomous variable with (1 = Yes, 0 = May be). Hence, BLR is most suitable for modelling such relationships (Roy et al, 2024). The second model is tested for its robustness using the Confusion Matrix and Machine Learning Performance parameters.

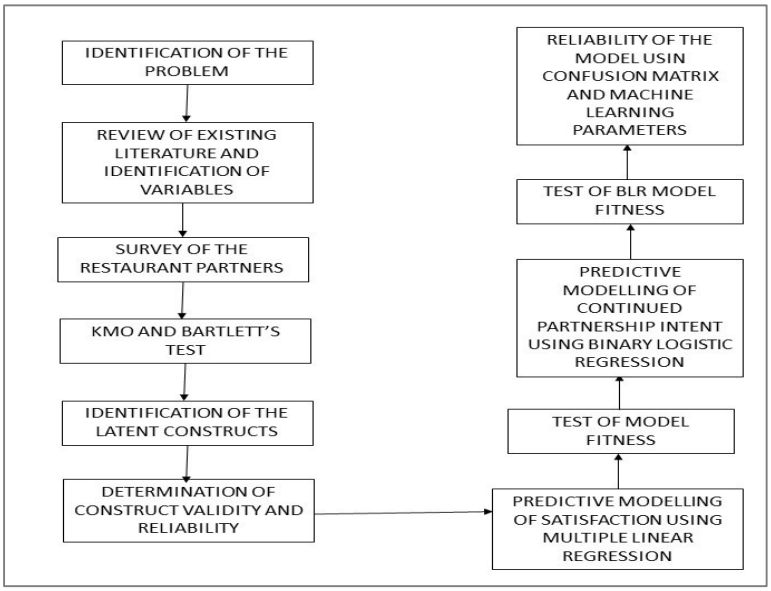


Fig 1: THE RESEARCH PROCESS FLOWCHART

The reliability of the model was further examined using the Confusion Matrix and the Receiver Operator Characteristics (ROC) to conclude about the model's Accuracy, Precision and Sensitivity using the expressions as given in Fig 2 below.

$$\text{Precision} = TP/(TP + FP)$$

$$\text{Recall (Sensitivity)} = TP/(TP + FN)$$

$$\text{Accuracy} = (TP + TN)/N(TP+TN+FP+FN)$$

$$\text{Specificity} = TN/(TN + FP)$$

They are all the performance parameters of the Machine Learning Predictor Model extracted from the two by two-confusion matrix.

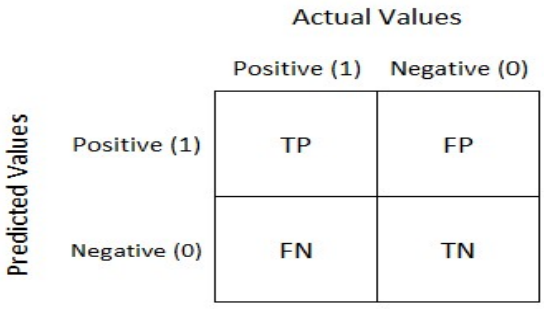


Fig. 2 CONFUSION MATRIX

Where,

TP = count of True Positive events

TN = count of True Negative events

FP = count of False Positive events

FN =count of False Negative events

N = the total no. of Observations/ events

Findings and Analysis

Construct Identification using *Exploratory Factor Analysis:* The responses of the 18 variables were tested using the KMO and Bartlett's test of Sphericity. The results collated in table 8.2 reveals KMO measures the sampling adequacy and the value of 0.789 suggests an acceptable value with which we can proceed for the Exploratory factor Analysis. The significant Bartlett's test of sphericity ($p=0.000 < 0.05$) re-emphasizes the data fitness for exploratory factor analysis (EFA)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.789
Bartlett's Test of Sphericity	Approx. Chi-Square	642.095
	df	153
	Sig.	.000

Table 2 : KMO and Bartlett's Test

The communalities extracted using the Principal axis factoring Method are as follows.

Table 3 Communalities

	Initial	Extraction
On boarding Process	.842	.737
Documentation during on boarding	.874	.859
Initial Training	.719	.654
Customer support service	.810	.580
Comm. Regarding Updates	.707	.758
Solution to the Issues	.761	.585
Platform Operation	.637	.510
Order management	.792	.646
Update of menus	.809	.714
Increase of sales	.509	.377
Attraction to Customers	.611	.532
Promotional Benefits	.765	.736
Commission Rates	.647	.585
Pricing Structure	.744	.607
Platform Fees	.790	.681
POS integration	.775	.737
Technological Advantages	.765	.749
Analytical Tools	.695	.535

Extraction Method: Principal Axis Factoring.

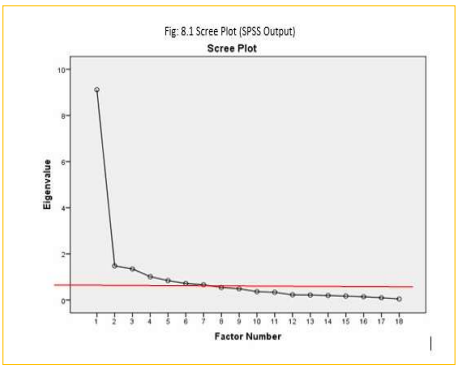
The initial Eigen values and the rotated sums squared loadings derived from the PAF depicted in table 8.4 below shows there are 4 latent factors that can be extracted out of these 18 variables.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.114	50.633	50.633	8.775	48.749	48.749	3.622	20.124	20.124
2	1.480	8.221	58.854	1.115	6.194	54.943	3.269	18.159	38.284
3	1.346	7.479	66.333	.990	5.499	60.443	2.664	14.798	53.081
4	1.012	5.622	71.954	.704	3.914	64.357	2.030	11.275	64.357
5	.841	4.675	76.629						
6	.717	3.982	80.611						
7	.663	3.686	84.296						
8	.546	3.033	87.330						
9	.487	2.704	90.033						
10	.363	2.019	92.052						
11	.335	1.861	93.913						
12	.226	1.257	95.170						
13	.218	1.211	96.381						
14	.196	1.091	97.472						
15	.170	.947	98.419						
16	.142	.790	99.210						
17	.098	.542	99.752						
18	.045	.248	100.000						

Extraction Method: Principal Axis Factoring.

Double-click to activate



Further using Varimax Rotation with Kaiser Normalisation the 4 component factors in the matrix computed are as follows:

Table 5: Rotated Factor Matrix[a]

	Factor			
	CRM	PF	OHE	OD
Onboarding Process				0.862
Documentation during onboarding				0.712
Initial Training	0.686			
Customer support service	0.858			
Comm. Regarding Updates	0.752			
Solution to the Issues	0.989			
Update of menus	0.856			
Commission Rates	0.727			
Platform Operation			0.943	
Order management			0.605	
Attraction to Customers			0.966	
Promotional Benefits			0.986	
Platform Advantage		0.857		
Pricing Structure		0.567		
Platform Fees		0.820		
POS integration		0.712		
Technological Advantages		0.799		
Analytical Tools		0.980		

The 18 variables could be clubbed into 4 specific factors namely-

Component 1: Variables like Initial Training, Customer support service, Comm. Regarding Updates, Solution to the Issues, Update of menu, and Commission Rate, have high loadings on this component. This suggests that this component may represent aspects related to building relationships with the restaurant partners and named as **CRM Efforts**. It explains a considerable amount of variance in the dataset.

Component 2: Platform Advantages, Pricing Structure, Platform Fees, POS Integration, Technical Advantages, and Analytical Tools, have high loadings on this component. This component may represent factors related to features of the platform being used and can be named **Platform Features.**

Component 3: Variables like Platform Operations, Order Management, Attraction to the Customers, and Promotional Benefits have high loadings on this component. The component may represent aspects related to Platform Operations, Order Management, Attraction to Customers, and Promotional Benefits, and can be named as **Order Handling Efforts**.

Components 4: This component is strongly related to variables such as On boarding Process and Documentation during on boarding. These variables may represent aspects related to on boarding factors that can be named as **On boarding Dynamics**. This component explains a significant amount of variance in the dataset.

Table 9 : ANOVA TABLE

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	51.972	4	12.993	63.297	.000[b]
Residual	40.028	195	.205		
Total	92.000	199			

The ANOVA results displayed in table 9 above show that the regression model is statistically significant, with the predictors collectively having a strong impact on the dependent variable (Satisfaction Rate). The significance is 0.000, which is much less than 0.05 therefore making sure that the independent variables are significantly explaining the variations in the dependant variables.

Table 10 : Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.745	.285		2.613	.010
	CRM EFFORTS	.216	.067	.247	3.228	.001
	PLATFORM FEATURES	.713	.077	.624	9.272	.000
	ORDER HANDLING EFFORTS	.075	.074	.063	1.022	.004
	ONBOARDING DYNAMICS	-.126	.059	-.155	-2.142	.033

From the Table 10 above we can observe that the Beta coefficient of constant is +.745,CRM efforts is +.216, platform features is +.713, and order handling efforts is +.075, whereas on boarding dynamics shows -.126, and significance level of all factors are below 0.05 that

states that this regression model is statistically significant. The above values indicate while all the other 3constructs have a positive impact on the satisfaction score. The On boarding dynamics have a negative bearing on the Satisfaction score. That is the easier is the on boarding process the satisfaction in the relationship is higher.

Hence the Multiple Linear Regression Model stands as :

Model: $Y(satisfaction) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4$

Y(satisfaction) = 0.745(constant) + 0.216*(CRM Efforts) + 0.713*(Platform Features) + 0.075*(Order Handling Efforts) - 0.126*(On boarding Dynamics)

To sum up, the analysis identifies the key drivers of satisfaction, with actionable insights for improvement. The significance value of all the variables including the constant is less than 0.050, thus claiming the acceptance of the independent variables and their impact on the dependent variable Satisfaction score of the restaurant partners. The more efforts given in customer relationship management, order handling, and adding platform features helps to increase the satisfaction level of the restaurant partners. On the other hand if on boarding documentation and procedures is reduced then that helps to increase the level of satisfaction of the restaurant partners.

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.56817	5.22786	4.50000	.511044	200
Residual	-1.459164	1.145886	.000000	.448492	200
Std. Predicted Value	-1.823	1.424	.000	1.000	200
Std. Residual	-3.221	2.529	.000	.990	200

Table No.11 Residuals Statistics[a] a. Dependent Variable: Satisfaction Rates

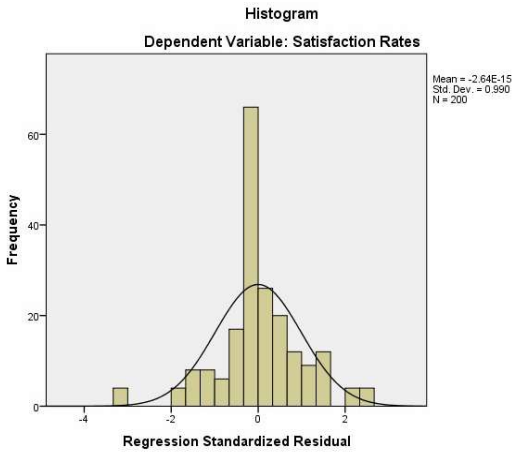


Fig:3 Histogram

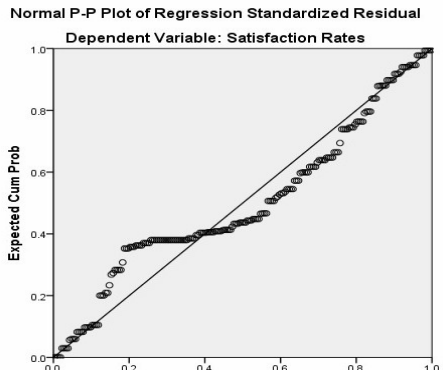


Fig:4 Residual chart

The residual statistics in Table 11and the histogram P-P plot suggest an acceptable standard residual plot. This further suggests that the model quite fits the given data. However, the adjusted R^2 value of 0.556 leaves a scope for further research to identify other explanatory variables which if incorporated would give a more robust model.

Predictive Modelling of Continued Partnership Intent:

To find out under the given circumstances whether the restaurant partner would continue the partnership with the Zomato food aggregation platform the question asked is:

"I would like to continue the partnership with Zomato for the next 5 years" The response is taken on an ordinal scale (1 = Yes, 0 =May be, -1 = No). The responses were only two (1= Yes and 0=Maybe). Therefore, the scale interestingly was translated to a dichotomous response only collated as in the table 12 below:

Table 12 : Responses to Continued Partnership Intent

Continued Partnership Intent	May be	45
	Yes	155

We have included 6 variables to check which affects Continued Partnership Intent namely : Tenure of association (ordinal), and the four continuous scale construct variables On boarding Dynamics, CRM Efforts, Platform Features, Order Handling Efforts and the satisfaction scores (continuous variable). The table 13(a) below points out the impact of each of these variables.

Table 13(a) : Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Satisfaction_Rates	4.731	.945	25.041	1	.000	113.431
	PLATFORM FEATURES	-3.532	1.030	11.763	1	.001	.029
	Tenure_Assoc	.683	.936	.533	1	.465	1.980
	ON BOARDING DYNAMICS	.683	.542	1.587	1	.208	1.980
	CRM EFFORTS	.164	.655	.062	1	.803	1.178
	ORDER HANDLING EFFORTS	1.097	.835	1.727	1	.189	2.996
	Constant	-12.120	2.356	26.463	1	.000	.000

a. Variable(s) entered on step 1: Satisfaction_Rates, PLATFORMFEATURES, Tenure_Assoc, ONBOARDINGDYNAMICS, CRMEFFORTS, ORDERHANDLINGEFFORTS.

It is evident therefore that only the satisfaction rates and concern for Platform features have a significant impact. So the resultant variables and the model are collated as below:

Table 13(b) : Variables in the Equation							
		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Satisfaction_Rates	4.657	.867	28.839	1	.000	105.276
	PLATFORM FEATURES	-2.013	.760	7.014	1	.008	.134
	Constant	-10.288	1.909	29.043	1	.000	.000
a. Variable(s) entered on step 1: Satisfaction_Rates, PLATFORMFEATURES.							

$$\log\left(\frac{\mathbf{p}}{\mathbf{1-p}}\right) = -\mathbf{10.288} - \mathbf{2.013}(\textbf{Concern for Platform features}) + \mathbf{4.657}(\textbf{Satisfaction rate})$$

Where, **p** is the probability of the binary outcome {**p** = P(Y_c=1), and Y_c = Intention to continue the partnership with Zomato . It is a dichotomous variable with Yes (=1) and May be (=0)}. Interesting though that the variable Concern for Platform features bears a negative relationship with the Continued Partnership Intent. Which leaves an insight for Zomato operations in the Durgapur Region. Somehow the restaurant partners in the territory do not seem to be much tech savvy. More educative trainings and enhanced features may further be required to coax and nurture the existing partnership for effective CRM in the years to come.

The Omnibus test for the model coefficients was found to be significant followed by a significant pseudo R2 value. "Cox and Snell R2" = 0.623 and "Nagelkerke R^2" of 0.595.

Table 14: SPSS Output for "Omnibus Tests of Model Coefficients"				
		χ^2	df	Significance
Step 1	Step	101.508	2	.000
	Block	101.508	2	.000
	Model	101.508	2	.000

Table 15: SPSS output for "Model Summary"			
Step	"-2 Log likelihood"	"Cox & Snell R Square"	"Nagelkerke R Square"
1	255.399[a]	.623	.607
a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.			

The table16 below suggests that in our case the Chi-square (χ^2) value is 3.283 with a "degree of freedom" (d.f) = 5 and "significance p value" of 0.830 which suggests a "satisfactory fit of the model to the dataset".

Table 16 : SPSS output "Hosmer and Lemeshow Test"			
Step	χ^2	df	Sig.
1	3.283	5	.830

The SPSS output contingency table (Table 17) below too suggests that "the model is a good fit" for the existing data

		Continued Partnership Intent = May be		Continued Partnership Intent = Yes		Total
		Observed	Expected	Observed	Expected	
Step 1	1	20	18.820	0	1.180	20
	2	14	11.851	6	8.149	20
	3	3	6.431	17	13.569	20
	4	0	3.756	20	16.244	20
	5	3	2.840	53	53.160	56
	6	4	.867	24	27.133	28
	7	1	.435	35	35.565	36

Table 17: Contingency Table for Hosmer and Lemeshow Test

Reliability of the model with Machine Learning performance parameters

Predicted Intention	**Observed Intention**	
	Yes (1)	May be (0)
Yes (1)	**152**(True Positive)	**12** (False Positive)
May be (0)	**3** (False Negative)	**33**(True Negative)

Table 18 : Confusion matrix of the predictor model

The confusion matrix in Table 18 above generated from the classification model and the summary statistics in Table 19 below collate the performance parameters of the predictive model thus developed using Binary Logistic Regression .

Number of Cases	Number Correct	Accuracy	Precision	Sensitivity	Specificity	Pos Cases Missed	Neg Cases Missed	Empiric ROC Area	F1 Score
200	185	0.925	0.927	0.981	0.733	3	12	0.857	0.953

Table 19: Summary Statistics Machine Learning performance parameters

1.Accuracy: In machine learning, accuracy is a metric that measures how often a model's predictions are correct. Accuracy can be measured as a percentage or on a scale of 0 to 1,

with higher values indicating better performance. So accuracy measure of > 90% is ideal and realistic, and is consistent with industry standards. In our case the value *it is **92.5% that means out of 200 responses 185 responses were correctly predicted by the model** and is consistent with the industry standards according to the accuracy value.*

2.Overall Recall Value/ Sensitivity: Recall is a metric that measures how often a machine learning model correctly identifies positive instances (true positives) from all the actual positive samples in the dataset.. This metric measures the ability of the model to correctly identify positive cases.

A sensitivity of 98.06% means that the model identifies about 98.06% of the positive cases correctly. *The acceptable recall value is 0.8 or 0.9 and in our case, the value is **0.98** which is acceptable according to Industry standards.*

3. Specificity: In machine learning specificity is a metric that measures a model's ability to correctly predict negative cases out of all the values that are actually negative.A specificity of 73.33% means that the model identifies about 73.33% of the negative cases correctly.

4. Positive Cases Missed: 3

There are 3 positive cases missed, implying perfect identification of positive cases in this context.

5.Neg Cases Missed:12

12 negative cases were incorrectly classified as positive.

6.AUC Interpretation ROC Parameter: The area under the ROC curve (AUC) is a machine learning metric that measures how well a model ranks positive and negative examples. The AUC score ranges from 0 to 1, with higher scores indicating better model performance. In interpretation of ROC parameter 0.9-1.0 is considered as excellent performance in our case *the AUC value is **0.857** which signifies Good Performance of the model.*The empirical ROC area is equivalent to the AUC (Area Under Curve), which measures the model's ability to distinguish between classes. An **AUC of 0.857** indicates good discriminatory ability.

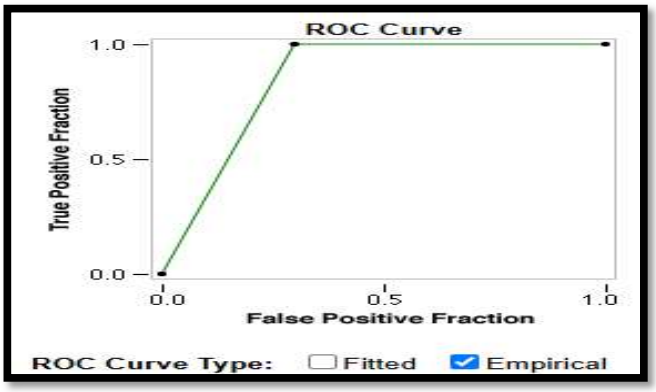


Fig 5 : ROC Curve

Discussion

The findings underscore the importance of delivery efficiency and affordability in shaping consumer preferences in tier-3 markets. Zomato's edge in delivery time aligns with studies highlighting logistical efficiency as a critical success factor in food aggregation. However, Swiggy's advantage in restaurant variety suggests an opportunity for Zomato to onboard more diverse eateries in Durgapur.

For restaurant partners, Zomato's technological support and marketing visibility were highly valued. Local eateries appreciated Zomato's role in increasing online orders. However, concerns about high commission rates, limited menu customization options, and logistical challenges in reaching certain areas were significant limitations. These issues may deter smaller establishments with limited resources from partnering with Zomato.

Limitations for the Platform:

Commission Structure: High commission rates, ranging from 15% to 30%, can take away restaurant profit margins, particularly for small-scale eateries.

Technical Barriers: Many local restaurants struggle to adapt to Zomato's platform due to limited technical knowledge.

Sample Size: Although the study included 200 restaurant partners, responses may not fully capture the diversity of challenges faced by establishments in Durgapur.

Recommendations:

Flexible Commission Models: Zomato may consider introducing tiered or volume-based commission structures to make partnerships more financially sound for small and medium-sized restaurants.

Training and Support: Providing technical assistance and training for restaurant owners to manage online orders effectively can increase participation.

Localized Marketing Strategies: Zomato should tailor marketing initiatives to promote local cuisines and small eateries, fostering community support.

Expansion of Delivery Network: Address logistical challenges by investing in optimized delivery routes and partnerships with local delivery services to extend coverage.

Customized Partner Programs: Introducing premium partner programs offering lower commission rates, priority visibility, and marketing assistance for high-performing restaurants could enhance loyalty and satisfaction.

These recommendations, if implemented, could strengthen Zomato's value proposition for restaurant partners, ensuring long-term collaboration and mutual growth.

Conclusion

This study highlights the priorities for Zomato's growth in Durgapur, enhancing restaurant partners' satisfaction through better facilities through the platform, reducing on-boarding procedures for small and medium-sized restaurants, and maintaining strong partnerships with local eateries through CRM efforts. By addressing standard commission rates and leveraging its technological tools, Zomato can secure its position in tier-3 markets. Future research should explore longitudinal trends in consumer preferences and the scalability of similar strategies across other regions.

The study has quite a number of limitations evolving from its methodology, scope, and findings. The myopic focus on the Durgapur market and the small sample size of just 200 restaurant partners with limited demographic representation do restrict generalizability. By examining only Zomato, the study overlooks other competitors. Further reliance on self-reported data introduces potential biases, and its cross-sectional design fails to capture long-term trends. This leaves ample room for scope of further research in the area.

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